REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—

A Coordination Facility Administered Jointly By

The Pacific Southwest Forest and Range Experiment Station of the Forest Service, U.S. Department of Agriculture and by the School of Forestry, University of California

For

NATURAL RESOURCES PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

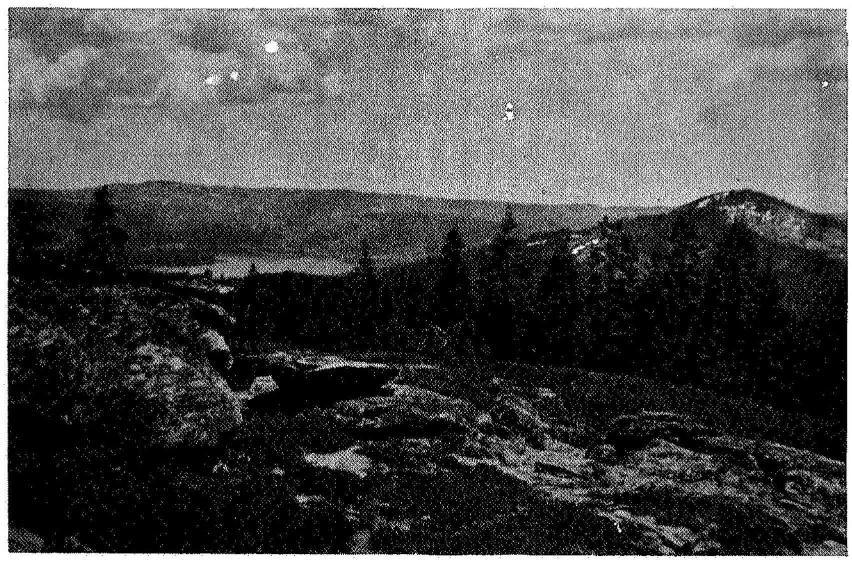
THE INTERPRETABILITY OF HIGH ALTITUDE MULTISPECTRAL IMAGERY FOR THE EVALUATION OF WILDLAND RESOURCES

By

William C. Draeger

School of Forestry
University of California

Annual Progress Report 30 September, 1967



The Bucks Lake NASA Test Site, located in the Sierra Nevada Mountains of California, contains a wide variety of wildland resources, including timberlands which are the primary factor in the economy of the area; brushfields which provide habitat for wildlife and which often have the potential for conversion to timberlands; grasslands suitable for grazing by domestic livestock; watersheds; and both present and potential recreation areas. Elevations within the test site varies from 3600 to 7000 feet, thus providing a number of climatic regimes which are reflected in the differing soil and vegetation types found in the area.

TABLE OF CONTENTS

ABSTRACT

High altitude multispectral imagery of the Bucks Lake Test Site in the Sierra Nevada Mountains of California was studied, and field data collections were made in an attempt to ascertain the optimum specifications for remote sensing imagery on which to identify and evaluate wildland resources. Examples of the information that can be extracted from various types of small scale imagery were prepared and discussed and a representative image interpretation guide for use in training interpreters was developed. Optimum image specifications were found to vary with both the resource involved and the type of management decisions to be made. It was concluded, however, that the best single image type for general purposes is that obtained using Ekta-Aero Infrared film in conjunction with a Wratten 12 filter. Of more flexibility, however, are several black-and-white photographic images in the visible and near infrared bands which can be studied individually, in concert, or converted into a color composite image by means of multicolor projection techniques. For specific applications such as soil moisture detection or study of geomorphology, sensors such as radar or thermal infrared detectors appear to be most advantageous.

ACKNOWLEDGMENTS

This research was performed under the sponsorship and assistance of the National Aeronautics and Space Administration for the Natural Resources Survey Program in Agriculture/Forestry, contract number R-09-038-002, by personnel of the Forestry Remote Sensing Laboratory, School of Forestry, University of California, Berkeley, California.

Presentation of the material contained herein has been possible through the cooperation of a number of individuals and organizations. Among the staff and students of the School of Forestry, University of California, who rendered vital service in the collection of ground data and compilation and interpretation of aerial imagery were David M. Carneggie, Donald T. Lauer, Eric Janes and Ruth Ormondroyd. Particular thanks is given to John W. Thomas, who assisted in the bulk of the field work and in preparation of the Appendix material

Acknowledgment is also given to Cartwright Aerial Surveys, Incorporated (Sacramento, California) for procurement of imagery of the Bucks Lake Test Site, and to Berkeley Commercial Photo Company, Berkeley, California, for assistance in obtaining ground photography and the preparation of illustrations used in this report.

THE INTERPRETABILITY OF HIGH ALTITUDE MULTISPECTRAL IMAGERY FOR THE EVALUATION OF WILDLAND RESOURCES

by

William C. Draeger

INTRODUCTION

Over two-thirds of the land surface of the earth is covered with some form of forest or rangeland vegetation. Most of this area can be classified as wildland, i.e., land not densely populated or intensively managed by man. For most wildlands, accurate resource inventories of the types necessary for management planning are either sparse or entirely lacking. It is apparent that as the human population of the earth increases, these wildlands will assume an ever-increasing importance as the source of resources which can be used to satisfy increasing human needs. As a source of wood and paper products, fuel, water, minerals, wildlife, forage for livestock and recreation, and as potential sites for producing food crops, these lands must be placed under a much more intensive management. With such management will come the need for both quantitative and qualitative data as to the existence and potential of the wildland resources at a level far in excess of what is presently available.

Experience has shown that one of the most efficient and inexpensive means of obtaining data pertaining to vast and inaccessible tracts of land is by means of aerial photographic techniques. In recent years it has been possible to augment these techniques through the use of many image-forming sensors other than the standard camera

AREAS OF MAJOR VEGETATION TYPES
THROUGHOUT THE WORLD

	Area in Sq. Miles	Percent of Total Land Area
Forests		
Tropical rain forest	3,800,000	7.5
Temperate rain forest	550,000	0.9
Deciduous forest	6,500,000	12
Coniferous forest	7,600,000	15
Monsoon (dry) forest	2,000,000	3.8
Thorn forest	340,000	0.6
Broad sclerophyll forest	1,180,000	2.1
Total forest	21,970,000	42
Grasslands		
High grass savanna	2,800,000	5.3
Tall grass savanna	3,900,000	7.5
Tall grass	1,580,000	3.1
Short grass	1,200,000	2.4
Desert grass savanna	2,300,000	4.3
Mountain Grassland	790,000	1.4
Total grassland	12,570,000	24
Deserts		
Desert shrub and grass	10,600,000	21
Salt desert	30,000	--
Hot and dry deserts	2,400,000	4.7
Cold desert (tundra)	4,400,000	8.3
Total desert	17,430,000	34

Table 1. Nearly two-thirds of the land surface of the earth has as its native vegetation some form of forest or grassland. Shautz, H. L., 1954. The Place of Grasslands in the Earth's Cover of Vegetation. ECOLOGY, 35(2):143-145.

(e.g., thermal infrared sensors and radar devices). In addition, earth-orbital vehicles capable of acting as the platforms for such sensors have evolved to the point where it soon may be feasible to make resource inventories utilizing imagery obtained from orbiting satellites.

The research discussed in this study is directed toward determining the extent to which accurate evaluations of wildland resources can be made on high altitude multispectral imagery such as may soon be obtainable from space. Consideration is given both to the general feasibility of making such evaluations and the specifications as to the type and resolution of imagery necessary to make evaluations of varying degrees of intensity. In addition, the procedure for the development of a key to wildland resources on small scale imagery is discussed.

JUSTIFICATION FOR RESEARCH

The initial step in management planning for any wildland area is that of obtaining an accurate inventory of the resources, present or potential. This often necessitates the procurement of suitable aerial imagery at a scale and resolution which will permit the trained interpreter to identify, delineate, and, if appropriate, to describe quantitatively the terrain features of importance to the land manager in the decision-making process. Until recently, the common procedure was to obtain panchromatic minus-blue photography at a scale of from 1/10,000 to 1/20,000 for such photo interpretation. Such conventional photography has indeed proved to be entirely satisfactory for a multitude of purposes. Among the tasks that have been performed quite regularly on conventional aerial photography are the development of maps of stratified vegetation types, with information as to timber volumes, species composition, stand structure or animal carrying capacity; the mapping of soil and geologic resources; the determination of existing and potential access systems; the delineation and evaluation of watersheds; and the estimation of recreation potential.

However, the procurement of conventional aerial photography of vast tracts of wildland is a very expensive and time consuming process. Furthermore, there has been a steadily increasing need for more intensive evaluations of wildlands that previously were either not photographed or, at best, were only partially covered. Consequently, research is needed to develop more efficient systems to procure imagery of wildland areas and to extract meaningful data from that imagery.

This research effort is designed to investigate the feasibility of evaluating wildland resources on high altitude multispectral imagery. Jensen and Colwell (1949) demonstrated that in certain cases a greater number of terrain features could be discerned when panchromatic and infrared photography were interpreted in unison than when either one of the two types of photography were interpreted alone. This concept of using two or more film types or sensors in conjunction, thus utilizing radiation in several portions of the electromagnetic spectrum simultaneously, has been termed "multiband spectral reconnaissance". Terrain features which exhibit similar tone values on photographic emulsions sensitive to wide portions of the spectrum (such as standard panchromatic film) may vary significantly in their reflection or emission characteristics in various narrow portions of the spectrum. Therefore, the use of several different narrow spectral bands in the image-forming processes will often allow such terrain types to be discriminated. One objective of this study has been to determine the particular spectral bands or combinations of bands which would most readily facilitate the identification of a number of terrain features of interest to a wildland manager; a related objective has been to demonstrate methods that might best be used in specifying the optimum imagery system for any particular array of terrain features.

The choice of the appropriate spectral bands to be used does not, however, completely solve the problems encountered in attempting to evaluate these resources in vast wildland areas. It has been estimated that it would require more than 15 million aerial photos to provide stereo coverage at the conventional scale of 1/20,000 of the 34 million square miles of forest and grassland on the earth. However, it would require only eleven thousand 9" by 9" photos at a scale of 1/750,000 taken from an earth orbital vehicle to provide coverage of the same area. In this regard, the present study has investigated the spatial resolution which such orbital systems would have to provide if meaningful interpretation were to be made of such imagery for wildland management purposes.

METHODS AND PROCEDURES

1. The Bucks Lake Test Site in the Plumas National Forest, located in the Sierra Nevada Mountains of California, was selected as a NASA Fundamental Test Site for Forestry to study wildland resources. This selection was based on the diversity of typical wildland resources found within the area, and on the large extent to which "ground truth" for these resources was already known.

2. During the year covered by the previous annual progress report (June 1, 1965 to September 30, 1966) extensive aerial imagery of the Bucks Lake test site was obtained. Panchromatic, Aerographic Infrared, Aerial Ektachrome, and Ekta Aero Infrared photography at scales of 1/10,000 and 1/30,000 was flown in June and September of each year. In addition, K-band radar imagery, 9-lens multispectral photography and 16 channel line-scan imagery composed of selected bands in the visible, near infrared and thermal infrared portions of the spectrum were obtained.

3. All of the imagery was carefully studied and extensive field investigations were carried out in an attempt to determine the ease and accuracy of identifying and mapping various wildland resources. The results of this earlier research were reported in the annual progress report of September 30, 1966.

4. During the year covered by the present report (August 30, 1966 to August 30, 1967) investigations were continued to determine the extent to which various economically important wildland resources could be identified and mapped on high altitude color spectrozonal imagery, with emphasis on the quantitative data that could be gathered utilizing specific types of imagery.

5. In order to adequately determine the degree to which various terrain features could be identified on the different image types, a series of more than 100 test plots within the Test Site were established. Each test plot contained at least one example of a particular feature of interest to the wildland manager which lent itself to possible interpretation by means of remote sensing techniques.

6. Each test plot was analyzed on the various image types available, and any distinguishing characteristics were noted. The plots were then visited by a field crew, and detailed data as to specific vegetative cover, rock and soil type, hydrologic characteristics, and other pertinent facts were recorded. In addition, terrestrial photographs were taken of all test plots from carefully selected camera stations.

7. The image interpretation and field data ("ground truth") were compared in order to determine the degree to which each image type furnished information pertinent to the wildland manager.

8. A large segment of the Bucks Lake Test Site was studied on small scale Ektachrome and Infrared Ektachrome aerial photography, and terrain type maps of this area were prepared. This necessitated not only an identification of terrain features, but an integration of the interpreter's findings into a workable system of classification of land areas. The areas were delineated on the basis of vegetation type, vegetation density and, in the case of timbered areas, average crown diameter. It was felt that in most cases such delineations also would reflect differences in soil and geology, and available moisture and land use patterns.

9. A field crew visited each of the areas that had been delineated and typed on the imagery, and data as to vegetative type, soil and geology, soil productivity, available moisture, past and present use, timber volumes, animal carrying capacity, aspect, steepness of slope, etc., were recorded and ground photographs were taken.

10. The photo typing and field data were compared in an attempt to determine the feasibility of performing such typing and delineation on small scale imagery. In addition, investigations were performed to determine the extent to which one might develop keys to the interpretation of numerous wildland resources on various types of remote sensing imagery.

11. Investigations also were undertaken to determine the degree to which fluctuations in reservoir capacity could be ascertained on small scale imagery. Measurements of variation in shoreline configuration of Bucks Lake were made on sequential photography. These measurements were correlated with actual fluctuations of lake volume and depth as recorded for the same dates by the reservoir administrators.

12. Photography of the higher elevation portions of the test site obtained in early June of 1965, 1966 and 1967, was examined in an attempt to determine the degree to which snow retention patterns and total volume of snowpack could be ascertained on small scale imagery. Corresponding "ground truth" was provided by the Pacific Gas and Electric Co., at several snow courses within the test site.

13. Experimentation with image enhancement by means of color projection techniques was carried out utilizing the nine-lens multispectral imagery previously obtained. Information that could be extracted from standard Ektachrome and Infrared Ektachrome photography, multispectral black-and-white photography and color enhanced images was analyzed to determine the degree to which color enhancement techniques are useful as an interpretation tool. Enhancement was performed by projecting several multispectral positive transparencies through appropriate colored filters onto a viewing screen. The objective was to determine whether

each feature on the photos would exhibit a unique color on the color composite image dependent on the "tone signature" of that feature on the various black-and-white transparencies.

14. A number of 70mm color transparencies of wildland areas obtained from earth-orbital altitudes by the Gemini astronauts were studied, and information of interest to the wildland manager that could be extracted from such imagery was noted.

DISCUSSION

A. Basic Considerations

The emphasis in the research conducted during the period covered by this report, September 30, 1966 to September 30, 1967, has been on determining the feasibility of obtaining quantitative data pertaining to wildland resources. An earlier phase of this project, as reported in the Annual Progress Report of September 30, 1966 had been primarily concerned with the identification of specific terrain features found in wildland areas. This was considered appropriate, since the first step in any operational photo interpretation project of this type should be that of making a qualitative evaluation of the area in question. However, in most cases, if definite management decisions are to be made, at least some quantitative data must be extracted from the imagery.

Wherever possible, investigations have been carried out using small scale imagery. The spatial resolution that will be obtainable from earth-orbital vehicles in the near future is subject to conjecture, and is limited by both technological and political factors. However, ground resolution of approximately one meter is probably the best that can be expected from orbital altitude within the next decade (assuming, for example, a 120-inch focal length camera with negatives that will resolve 100 line pairs per millimeter, at an altitude of 150 miles). In addition, it was realized that only a very limited three-dimensional stereo effect will be obtainable on imagery that is taken at orbital altitudes. Consequently, no reliance was placed on stereoscopic viewing in the present tests--all interpretations being done from single photographs rather than stereoscopic pairs. The Ektachrome and Infrared Ektachrome photography that was used in these investigations, having a scale of 1/30,000 and a resolution of approximately 40 lines per millimeter, closely approximates the resolution expected from orbital imagery. One argument that might be raised against relating information derivable from such imagery with that derivable from earth-orbital imagery is that atmospheric attenuation would be a more serious problem from orbital altitudes than from standard flight altitudes. However, at an altitude of 20,000 feet, more than 50% of the earth's atmosphere is below the vehicle, and at 30,000 feet the camera is looking through nearly 70% of the atmosphere (see Figure 1). Thus imagery taken from this altitude suffers from an attenuation problem roughly comparable to that which is likely to be encountered on imagery taken from orbital altitudes.

Probably the first imaging systems to be put into orbit for natural resources survey purposes will be of relatively low resolution (200 foot ground resolution is often the suggested value). It appears likely that such imagery will be valuable for making gross qualitative evaluations of earth resources, such as mapping of broad vegetation or soil types. Such imagery also would be very useful in a three-stage sampling pro-

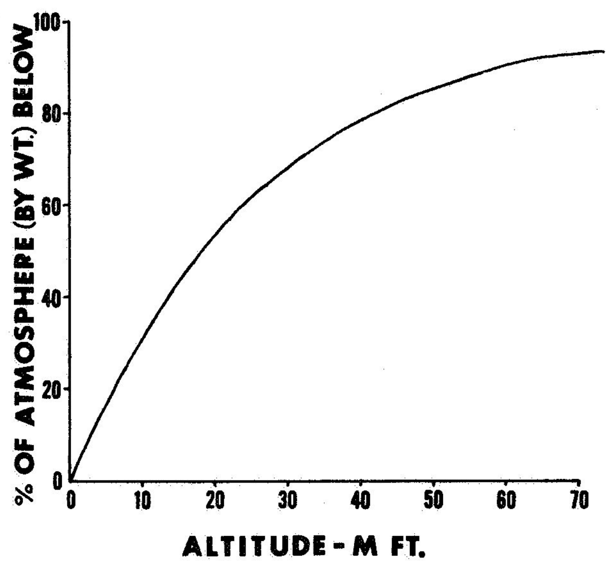


Figure 1. On imagery obtained from an altitude of 25,000 feet, nearly 60% of the earth's atmosphere is contributing to attenuation of the signal, and at 40,000 feet nearly 80% of the atmosphere is below the vehicle. Thus, atmospheric attenuation problems to be encountered from orbital altitudes can be closely approximated using conventional aircraft as the sensor platform.

cedure that has been visualized, wherein certain areas covered by the low resolution system are also imaged by a high resolution orbital system, and selected portions of these areas are, in turn, sampled by means of conventional aerial photography and/or on-the-ground checks. It is apparent that in such a sampling procedure, one of the greatest benefits to be derived from any orbital imaging system would be the ability to designate areas of interest that could then be investigated with a higher resolution system.

In the case of low resolution imagery, perhaps the only useful parameter for distinguishing between terrain types would be tone or color, as governed by the signal strength emanating from the feature being imaged. Only as resolution increases do textural differences become apparent, although in borderline cases texture may well contribute to the apparent tone (as, for example, when a mottled black and white feature appears grey on small scale imagery). Thus, in this study, tone or color has been considered to be the most significant characteristic of a particular terrain type, while texture or pattern is of secondary importance. A third image parameter or characteristic of a terrain type which often is not discussed is its relationship to other types. It is for this reason that a photo interpreter who is familiar with the wildland resources can often extract more information from an image than an interpreter not familiar with the resources in question. It should be noted that, while in the following discussion each general resource group (e.g., vegetation, soils, water, etc.) is discussed more or less separately, in many cases it is impossible to completely isolate one resource in the discussion since the interpretation of one resource is often linked with the interpretation of another, as when an identification of vegetation type yields clues to the underlying soil type.

In attempting to describe the appearance of a particular terrain feature, wherever possible a photo example has been provided. It has been found that for several reasons a subjective description of a feature is often quite unsatisfactory. Different interpreters quite often "see" a particular tone or color in different ways and, in addition, the word description of a given color often has different connotations for different persons. It is sometimes possible to use grey-scale or color chip references with which to compare the terrain feature in question; however, this is not generally satisfactory when working with color transparencies. Furthermore, differences in atmospheric conditions, film age, exposure and processing are often such that direct comparisons between exposures is impossible, although this problem can sometimes be somewhat alleviated through the use of internal grey-scale references in the case of black-and-white imagery. Also, a word description of a particular texture and pattern is often construed in different ways by different readers. Thus it is felt that whenever an actual photo example can be supplied to accompany a word description, it should be done. In addition, it should be remembered that the appearance of a specific feature may vary on different examples of the same type of imagery and often only through experience can the interpreter learn to deal with such variability.

B. The Vegetation Resource

1. The Timber Resource

The wildland resource manager sometimes seeks to develop a given area primarily in terms of timber production. In such instances, he must have at his disposal a great deal of quantitative data pertaining to the land in question and the forests on it before he is in a position to make any decisions relevant to the management of his lands. Among the types of information generally desired by the manager are: (1) present distribution of timber volume, (2) present distribution of forest tree species, (3) the capacity of the land to support a timber crop (commonly referred to as site index), regardless of whether or not such a crop is actually present, (4) the extent to which the potential of the land is presently being utilized (commonly referred to as stocking), (5) the rate at which the forest stands are increasing in volume, height and/or stem diameter with time (growth), (6) the degree to which management practices have previously been undertaken in the area, and (7) other factors which might affect management decisions, such as forest fire hazards, feasibility of developing a road system, proximity to product processing centers, etc. Only after such information has been gathered and studied can cutting schedules be set up, allowable cut and rotation age calculated and conversion of unstocked lands and improvement of poorly stocked lands begun.

Certainly not all that needs to be known by a forest manager can be derived from even large scale aerial photography. However, when utilized to its fullest potential, even small scale multispectral imagery can be of invaluable assistance to the land manager, in terms of both the data that can be extracted directly from the imagery and the increased efficiency in the gathering of ground data if aerial imagery is used as a guide.

a. Timber Volume and Stocking

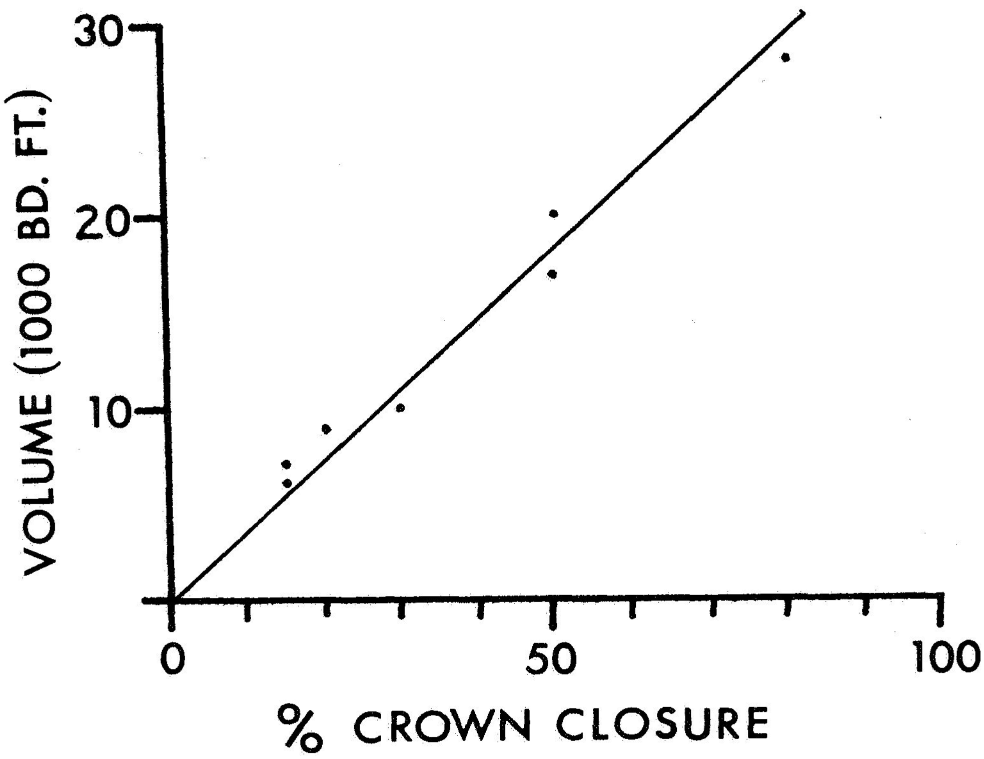
A number of different procedures for estimating timber volume directly from aerial photographs have been developed and tested; however, all such methods involve height measurements which cannot be made on small scale imagery such as would be obtained from orbiting vehicles. A study was initiated, therefore, to investigate the relationship between those photo parameters that would be available on small scale multispectral imagery and timber volume and stocking. The two characteristics of a forest stand that can be quantified on non-stereo imagery and that may be related to timber volume are percent crown closure (the percentage of the total ground area of the stand that is obscured by crowns of commercial species when viewed from vertically above), and average crown diameter. Eight representative stands that had been previously delineated on the photography of the Bucks Lake test site were cruised by a field crew and timber volume estimates were made from their on-the-ground measurements. Photo interpreters independently classified the same stands on the basis of crown diameter and crown closure of commercial conifers (less than 10 inches diameter at breast height). It was found that while the correlations between crown closure and volume, and between crown diameter and volume were not high enough to permit an accurate volume survey, definite relationships exist which will permit a determination of broad volume classes. Particularly in previously underveloped areas, such a gross determination would be a great help to the land manager by indicating where the more costly and time-consuming ground cruises might most profitably be carried out (see Figure 2).

In practice, forest stocking is expressed in terms of either the number of trees per unit area, the basal area of tree stems per unit area, or the wood volume per unit area. It is often possible to determine the number of tree stems per acre by direct count on small scale imagery provided the stand is relatively open and composed of trees larger than seedling size. A dense stand makes such counts impossible due to the fact that crowns in the understory are not visible from vertically above the stand.

b. Site Determination

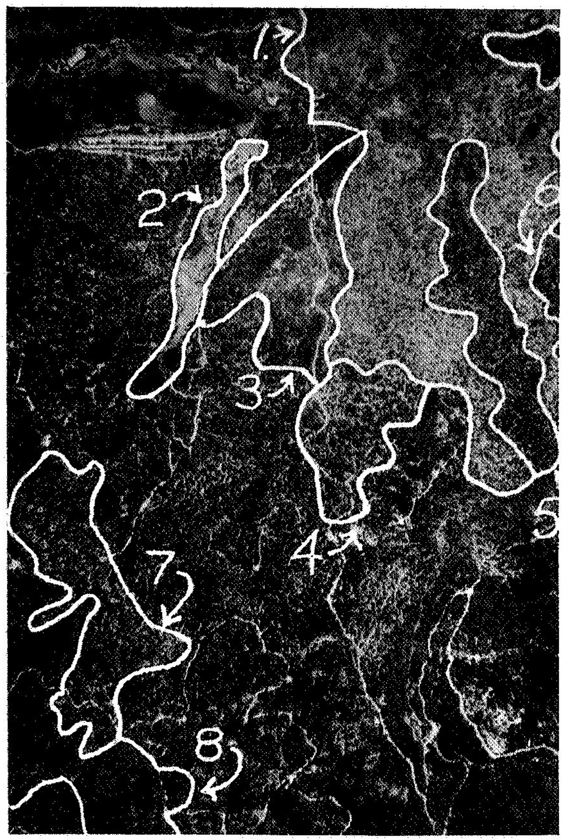
The site index, indicating the potential productivity of the soil of a given area in terms of growing a timber crop, is commonly determined by measuring the height of dominant trees at a given age. Usually such determinations are impossible from aerial imagery without the use of stereo viewing and the measurement of stereoscopic parallax. However, in those instances where the tree shadows are long (due to a low sun angle) and the ground is reasonably flat and level, measurements of shadow length can be made on individual photos and used to determine tree heights and site quality.

Often the productivity of a site can be deduced indirectly on small scale imagery. For example, particular tree species, species admixtures, or brush species often are indicative of site quality.

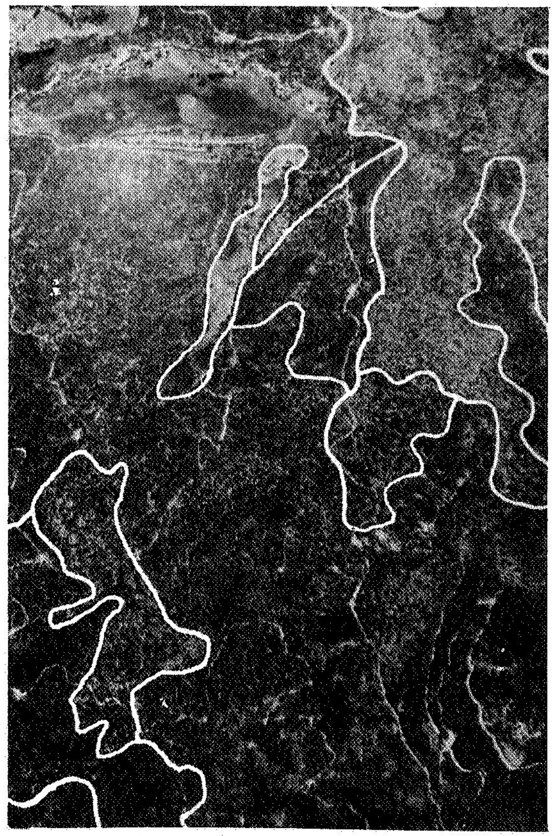


Stand	Volume (bd. ft.)	% Crown Closure	Av. Crown Diameter
1	7,000	5	28'
2	--	--	0
3	28,000	50-80	14'
4	17,000	20-50	19'
5	9,000	20-50	9'
6	6,000	5-20	7'
7	10,000	20-50	10'
8	21,000	20-50	15'

Figure 2. The timber types in Figure 3 were classified on the photos in terms of crown closure of merchantable conifers and average crown diameter. When plotted against gross timber volume (measured using conventional ground sampling procedures) stands were shifted to the upper or lower extremes of the crown closure class in which they fell on the basis of crown diameter. The resulting graph indicates that it might well be possible to classify timber stands into gross volume classes on the basis of non-stereo image interpretation, although certainly more precise methods would be necessary if intensive management planning was undertaken.



Ekta Aero Infrared, Scale 1/30,000



Aerial Ektachrome, Scale 1/30,000

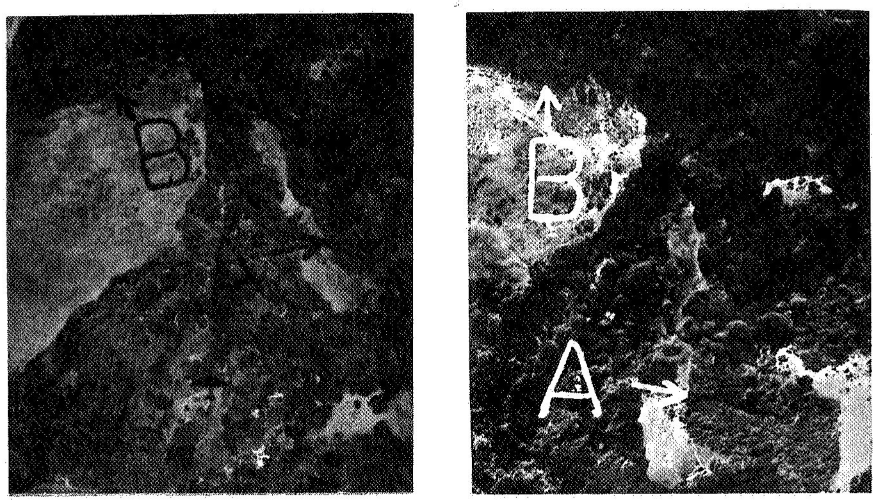
Figure 3. A portion of the Bucks Lake Test Site was delineated on small scale imagery, and crown closure and average crown diameter were measured in an attempt to determine the degree of relationship between these two parameters and timber volume, which was determined for each stand by means of conventional ground sampling techniques. See also Figure 2, which indicates the timber stand characteristics of each of the numbered areas.

Thus, the presence of Jeffrey Pine trees and wedgeleaf ceanothus bushes in admixture at the Bucks Lake area indicates a low site quality. Also, particular soils or geomorphologic conditions are often related to potential productivity. For example, serpentine-derived soils in the Bucks Lake Area have low productivity, partly because they contain toxic amounts of manganese and nickel. Finally, the presence of conditions indicative of past management or resource utilization activities might well provide a clue as to where site potential is highest within a given area.

c. Tree Species Identification

A major problem confronts an image analyst when evaluating the timber resource, either on space photography or on conventional aerial photography--that of making an accurate identification of the species of individual trees or of the species composition (i.e., the "type") of timber stands. If species identifications could be made from photo images, then the costly field operations essential to current survey practices could be totally (or partially) eliminated.

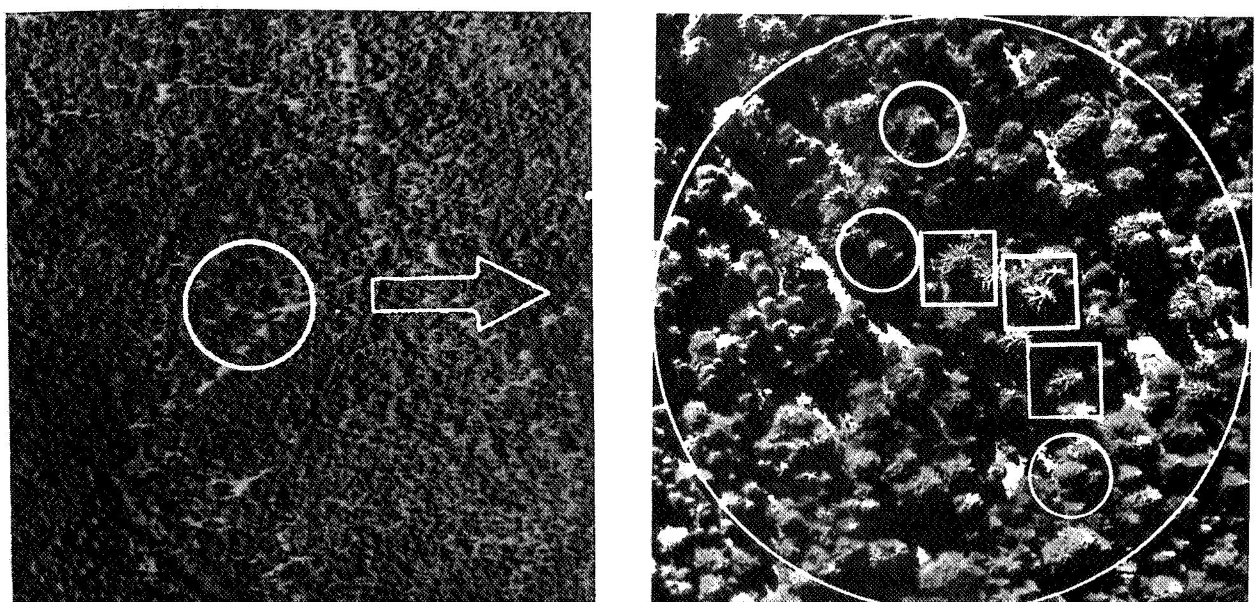
When remote sensing imagery of forested areas is taken to proper specifications, the individual tree species and stand types may exhibit unique tonal and/or morphological characteristics. The interpretability of these differences is often directly related to the following factors: (1) film-filter combination, (2) season of year, (3) age class of timber, (4) time of day, (5) atmospheric effects, (6) photographic scale, (7) resolution characteristics of the lens and film, (8) image motion, (9) stereoscopic parallax, (10) visual and mental acuity of the interpreter, (11) interpretation equipment



Ekta Aero Infrared Film
Summer Seasonal State

Ekta Aero Infrared Film
Fall Seasonal State

Figure 4a. Increased accuracy can be obtained when distinguishing deciduous from evergreen species if care is taken in selecting the optimum season of photography. Rhus diversiloba (poison oak) at B, when exhibiting a brilliant fall coloration, is easily separated from Bacharis pilularis (coyote brush) at A. At most other seasons of the year, these species are difficult to differentiate.



Aerial Ektachrome
Scale: 1/10,000

Aerial Ektachrome
Scale: 1/2,500

Figure 4b. Pinus lambertiana (sugar pine), circled, and Abies concolor (white fir), squared, can easily be identified on this Aerial Ektachrome photo, scale 1/2,500, using tree morphology as a guide. Littel detailed information is obtainable from conventional small scale photography; however, long focal length, high resolution systems planned for satellite reconnaissance theoretically could resolve detail small enough to reveal many morphological features of tree crowns.

and techniques, (12) film exposure and processing and (13) training aids. Lauer (1967) has systematically analyzed each of these factors, with an emphasis on their relation to spaceborne imagery, and has attempted to determine the optimum combination of factors for identifying several tree species and timber types in selected parts of the world (see Figure 4a and 4b).

2. The Forage Resource

The forage resource is but one of the many important resources found within forested wildland environments. Within other environments such as the nonforested tundra, savannah, steppe, and prairie, forage production is the primary and most important use of the land. The forage producing areas of the world vary in character from the sparse grass and brushlands of semi-desert regions, to the tall, dense perennial savannahs of semi-tropical regions. Throughout this spectrum of environments, the characteristics of the vegetation and their associated soils are so variable that it is difficult even to make generalizations concerning the optimum specifications for making improved inventories of the forage resource. It is perhaps sufficient here to cite the results of Carneggie (1967), "The Evaluation of Range Resources by Means of Multispectral Imagery".

In studying annual grassland ranges in California, Carneggie concluded that Ektachrome Infrared photography (Wratten 12) taken in the spring of the year, was most useful for separating low producing upland sites, from high producing bottomland sites. He did not, however, preclude the possibility that panchromatic and boack-and-white infrared (Wratten 89B) film, when superimposed through image enhancement techniques, could be equally useful. These same conclusions also applied to studies of a sagebrush-bunch grass range located in Lassen National Forest, California, where panchromatic, black-and-white infrared, Ektachrome, and Ektachrome Infrared film was examined. It was pointed out, however, that Ektachrome Infrared film is not universally the most useful film type for studying range environments. In particular, there is little advantage to be gained by using Ektachrome Infrared over panchromatic film when studying semi-arid regions, where the density of vegetation is sparse. In addition, 18 channel line-scan imagery of the sagebrush-bunch grass range was obtained by University of Michigan's optical mechanical scanner. The conclusions from interpretation of this imagery were: In spite of the poorer resolution obtained by this sensor, the wavelength band 162-.68u, was most useful for distinguishing the greatest number of vegetation-soil boundaries. Two near infrared bands, .72-.80 μ and .8-1.0 μ were equally useful for identifying the areas having dense lush meadow vegetation. Thermal infrared imagery, 8-13 microns, was useful for detecting moisture regimes which were not obvious on any other bands. Specific soil-vegetation types were more readily discerned on bands .32-.38 and 1.5-1.8, but in general were not as useful. Studies from a stationary platform at Yosemite National Park, California, demonstrated the usefulness of using thermal infrared imagery for consistently distinguishing meadow vegetation from other terrain types. In addition, it was possible to observe within and between season changes in the meadow which suggests the possible application of sequential remote sensing for monitoring and evaluating range conditions. Thermal infrared imagery of cattle and

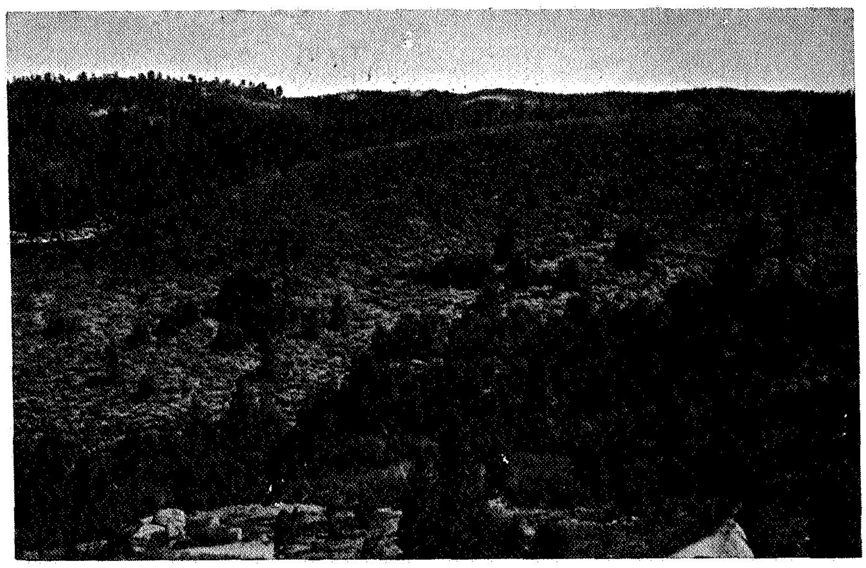


Figure 5. The dense cover of brush species seen in this photo is a potential source of browse for wildlife or domestic livestock. Notice that two principle brush species occupy the ridge site. Manzanita (Arctostaphyllos patula) dominates the upper site while snowbrush (Ceanothus velutinus), currently in flower, occupies the lower sites. They illustrate that important browse species can be distinguished by obtaining photography of them when they exhibit phenological differences. Dense, old brushfields such as this one could be managed for considerably higher game use by (1) burning to allow sprout regrowth, which is relished by deer, and (2) mechanical crushing or bulldozing to allow more accessible entry into the stand so that game could more fully utilize the tender new-growth produced each spring.

sheep, from a camera station on a 150 foot water tower, seemed promising for inventory of livestock or wildlife.

3. Vegetative Cover Typing

Often in the early stages of establishing a management plan for a previously underdeveloped wildland area, what is needed most is simply a vegetative type map on which gross boundaries between different vegetation communities have been delineated. Such delineations may be made at various levels of precision and accuracy, depending on either the needs of the land manager or the limitations of the imagery used. Figure 3 illustrates several forest stands which have been delineated on both Ektachrome and Ekta Aero Infrared photos at a scale of approximately 1/3,000. The criteria used in drawing boundary lines between types was percent of crown closure and average crown diameter. In an area such as the one illustrated, where boundaries between types are often not distinct, but rather consist of gradual changes in stand characteristics, and where visibility from the ground is limited due to the overstory vegetation, such delineations are often much more easily made on the aerial imagery than from the ground.

Thus far the discussion has centered around the use of conventional color or color-infrared imagery, but in some cases the use of other image types might be more desirable, from the point of view of ease of acquisition and/or ease of interpretation. Radar imaging systems have been discussed as one type of system that might well be used for vegetation mapping. The primary advantage of radar sensors derives from the fact that they are active systems operating in long wavelengths that are not usually attenuated by atmospheric conditions; hence they possess an all-weather, day-and-night capability. On flat terrain, where signal return is unaffected by topography, encouraging results have been reported using radar for vegetation mapping. However, where topography is fairly rugged, dissimilar returns from similar vegetation types have been observed. Figures 6 and 7 compare a conventional panchromatic and a K-band radar image of the Bucks Lake area. It can be seen that vegetation on slopes normal to the incoming radar signal (the flight line was to the north, or top of the imaged area) are consistently lighter in tone than similar vegetation types facing away from the incoming signal. However, radar can still be used in such areas if the interpreter remains cognizant of the effects of topography on the image.

When discussing the feasibility of vegetation mapping on satellite imagery, it is well to consider the possibility that imagery will be telemetered back to earth, thus precluding the use of conventional color films which would necessitate a film retrieval system. Nevertheless, often as much (if not more) information can be derived through the use of multiband spectral reconnaissance, wherein several black-and-white images, each utilizing a carefully selected narrow portion of the spectrum, are analyzed in concert. (Colwell, R. N., Some Practical Applications of Multiband Spectral Reconnaissance. American Scientist 49:1 March, 1961). Figures 8 and 9 illustrate the use of multiband imagery in vegetation mapping. Notice that in each case, while all terrain types can be distinguished on the basis of tone value, if all three black-and-white images are examined, no

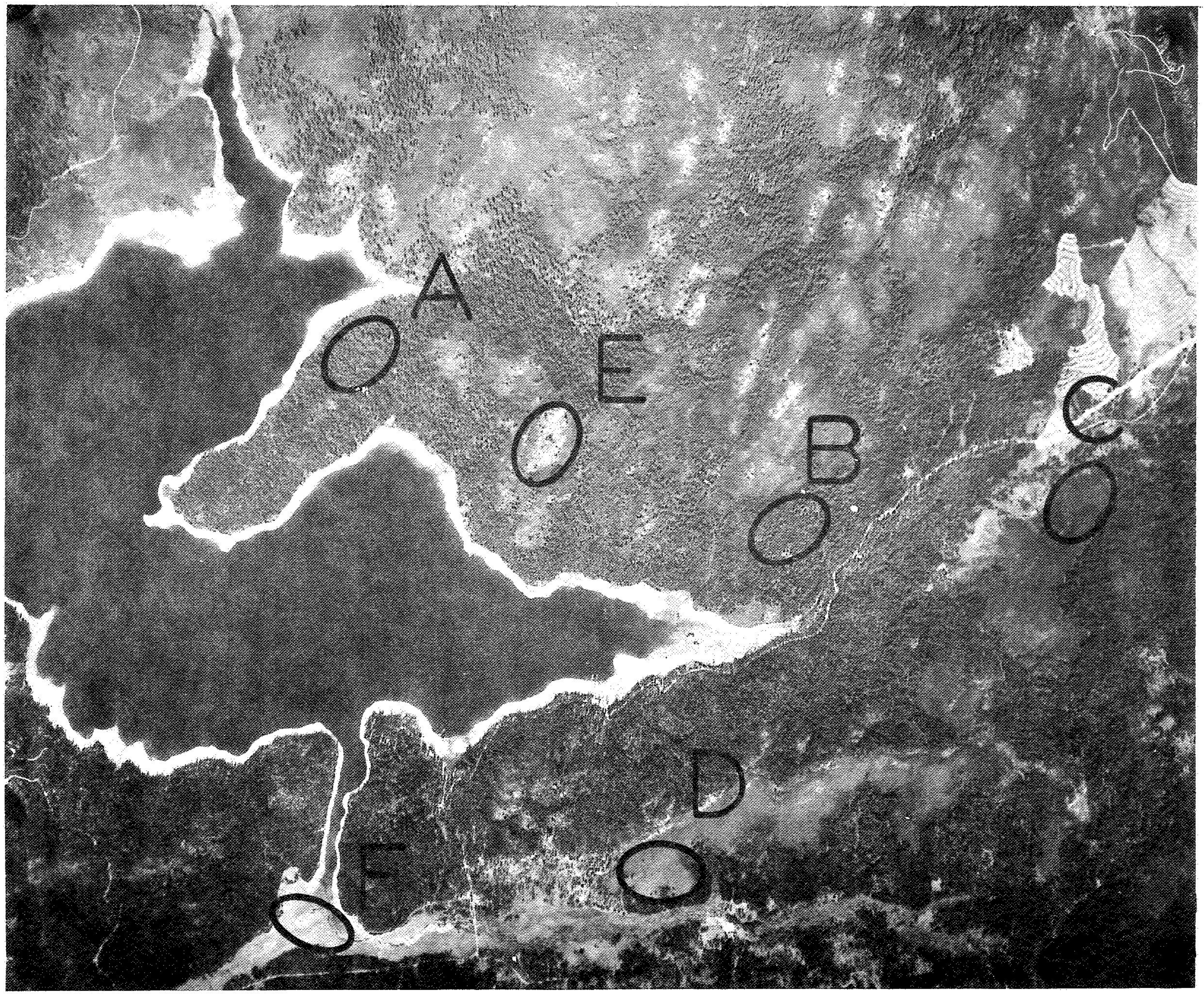


Figure 6. Panchromatic photograph, scale 1/25,000. Areas A and B are heavily timbered areas, C and D are brushfields, E is a rocky slope, and F is a meadow. Compare with Figure 7.

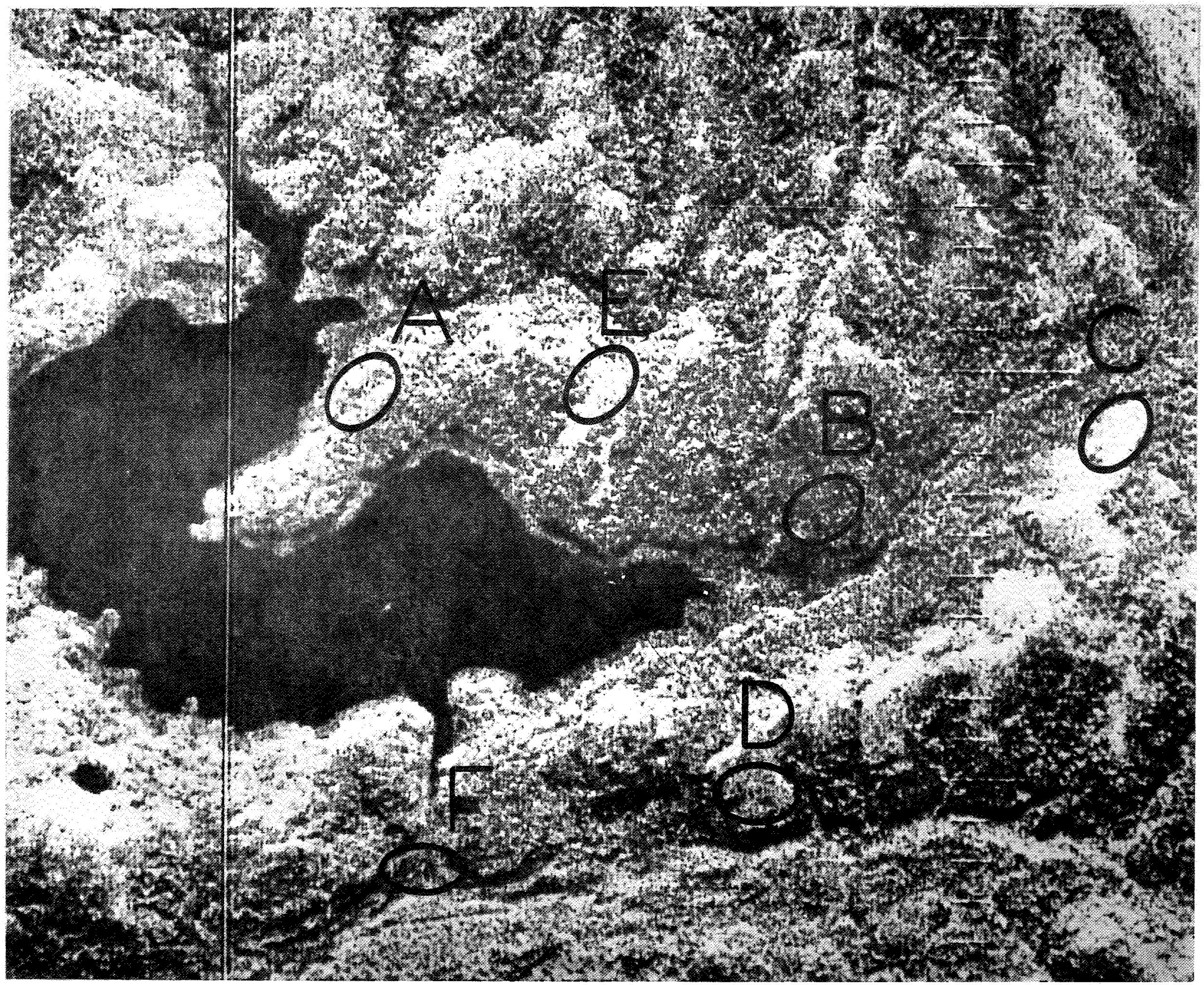
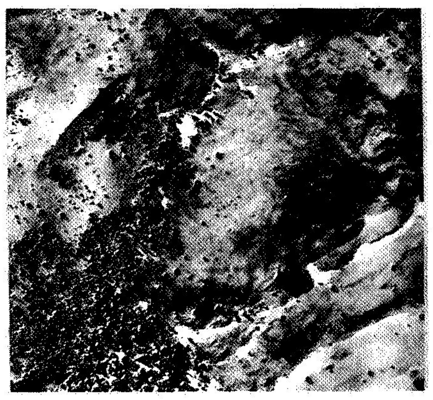


Figure 7. K-band radar, scale 1/25,000. Areas A and B are heavily timbered areas, C and D are brush-fields, E is a rocky slope and F is a meadow. Compare with Figure 6.

Panchromatic Film
520-580 microns

Panchromatic Film
660-720 microns



Infrared Film
750-950 microns

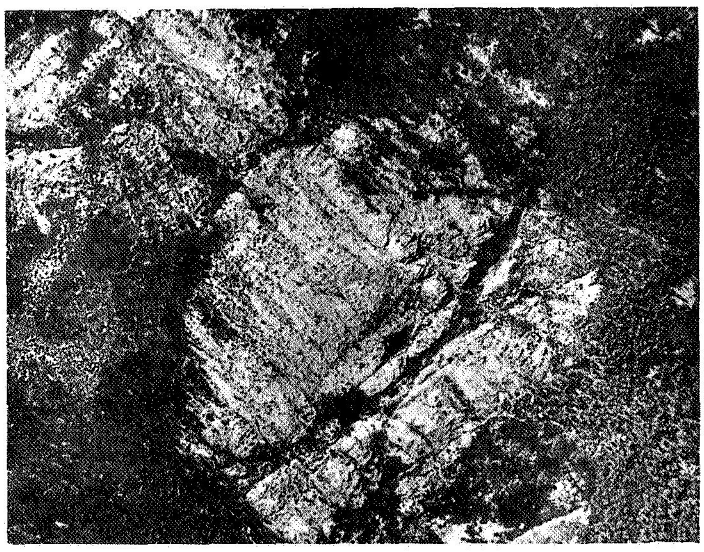
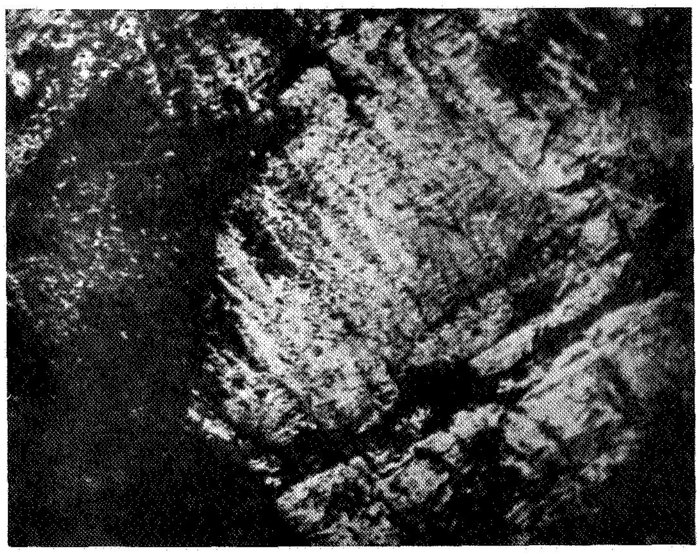


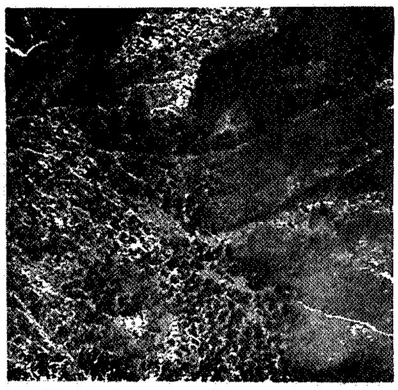
Image obtained directly, using Ekta Aero Infrared Film



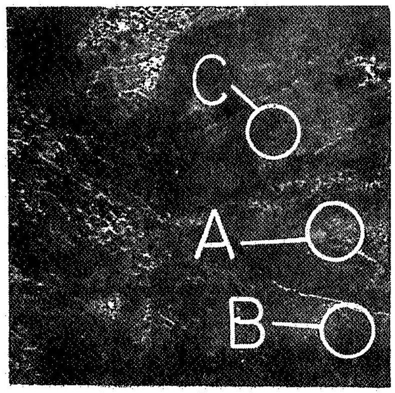
Multispectral color composite image obtained by by projecting through filters the three black-and-white images at top of page.

Figure 8. Multispectral black-and-white Ekta-Aero Infrared and color enhanced images of an area in the Bucks Lake Test Site. Notice that while no one of the black-and-white images allowed all of the terrain types present to be discriminated, the three images interpreted in concert make these discriminations possible. Notice also the degree to which it is possible to closely approximate an Ekta-Aero Infrared image by means of multicolor enhancement techniques. The black-and-white transparencies and colored filters used were:

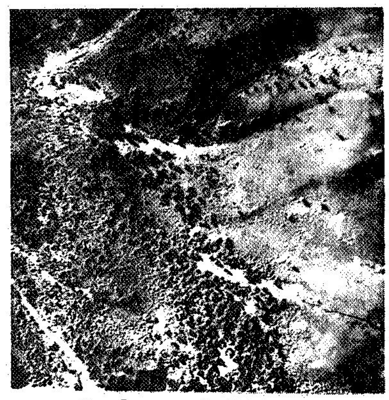
Spectral Band	Projection Filter
.52 - .58 u	blue
.65 - .72 u	green
.75 - .95 u	red



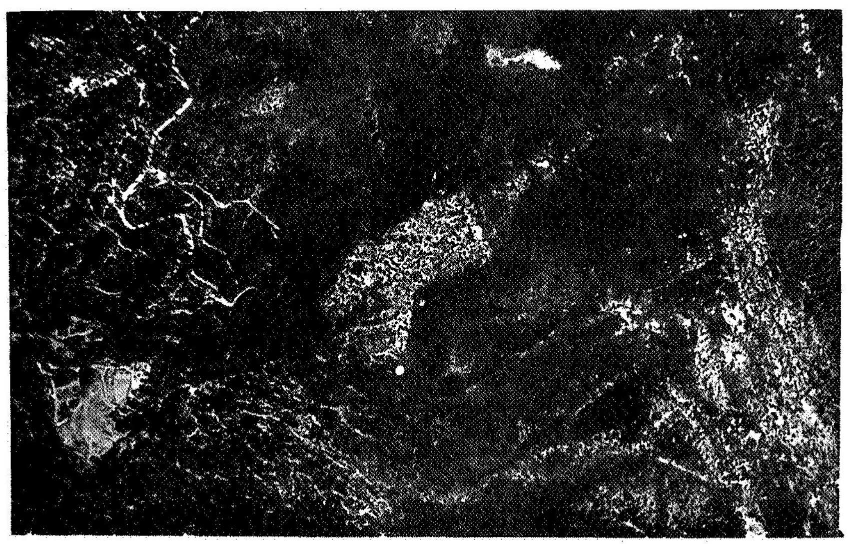
Panchromatic Film
520-580 microns



Panchromatic Film
660-720 microns

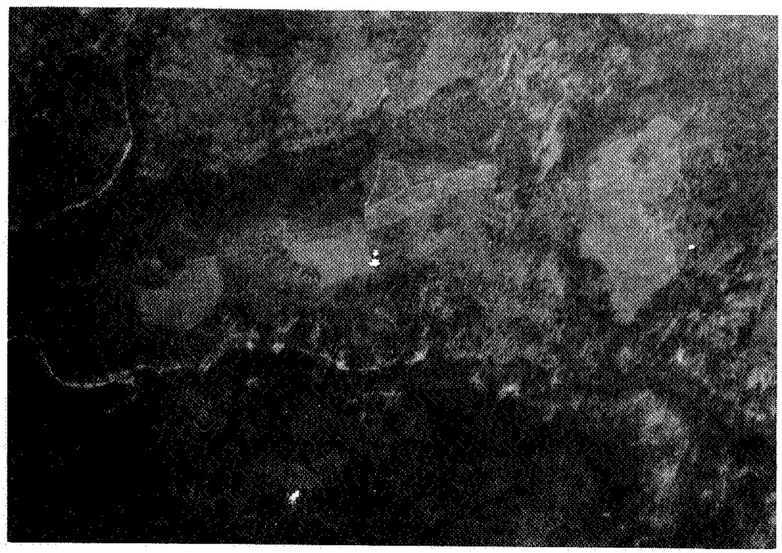


Infrared Film
750-950 microns



Ekta Aero Infrared Film

Figure 9. Multispectral black-and-white and Ekta Aero Infrared images of a portion of the Bucks Lake Test Site. No one of the multispectral images alone makes possible a discrimination of unproductive granite rocks (A) or brush species at B or C. All three can be discriminated, however, through use of either the color photo shown here or color composite photos made from multiband black-and-white imagery such as that appearing at the top of the page.



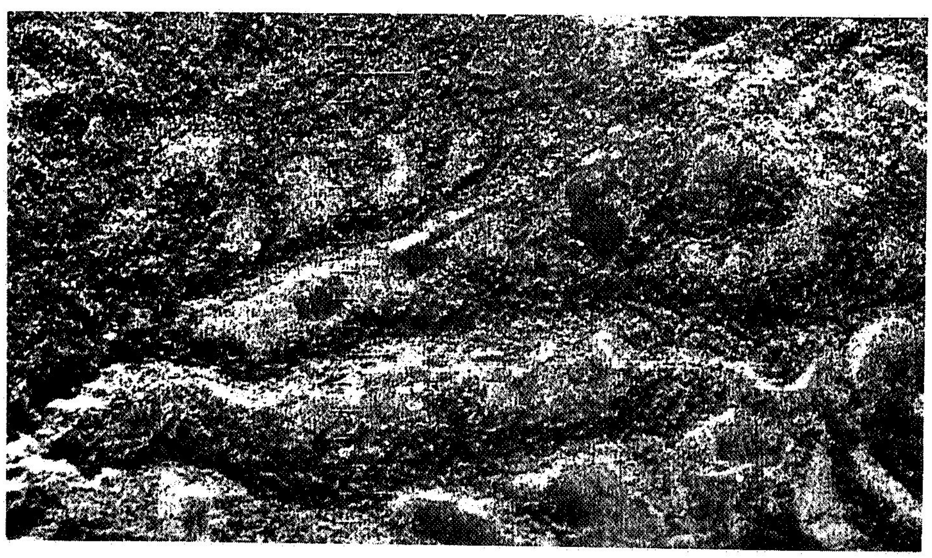


Figure 10. The top photo is a conventional Aerial Ektachrome print and the lower is a K-band radar image of the same area. While forested land, brushfields and cleared brushfields can be discriminated on both types of imagery, the radar affords an all-weather day-and-night capability that is not possible when using conventional aerial photography.

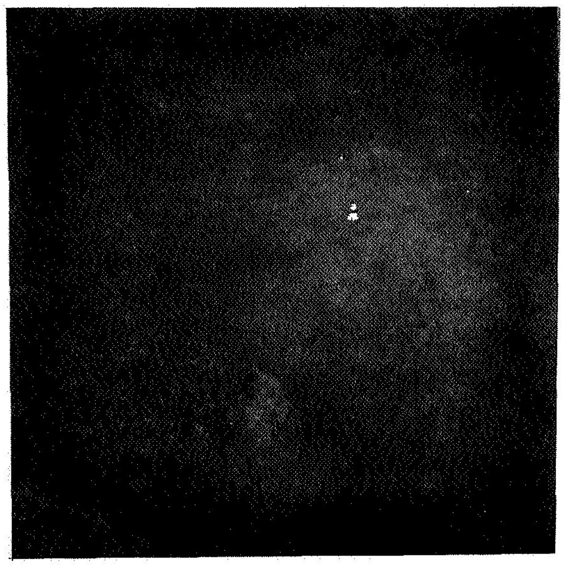


Figure 11. An Aerial Ektachrome photograph taken from earth orbit, illustrating the ease with which forest fires can be detected from space vehicles. (Note smoke plumes in bottom third of the photograph). Often early detection and rapid suppression are essential if a small fire is to be prevented from becoming a major holocaust that will destroy many thousands of acres of valuable timber or denude important brush-covered watersheds.

Figure 12. Prior utilization of resources can often be inferred through the use of small scale photography. The area in the top third of this photo has been logged, as can be deduced from the presence of sinuous logging roads and the sharp cutting boundary between the cutover stand and the virgin stand directly below it on the photo.

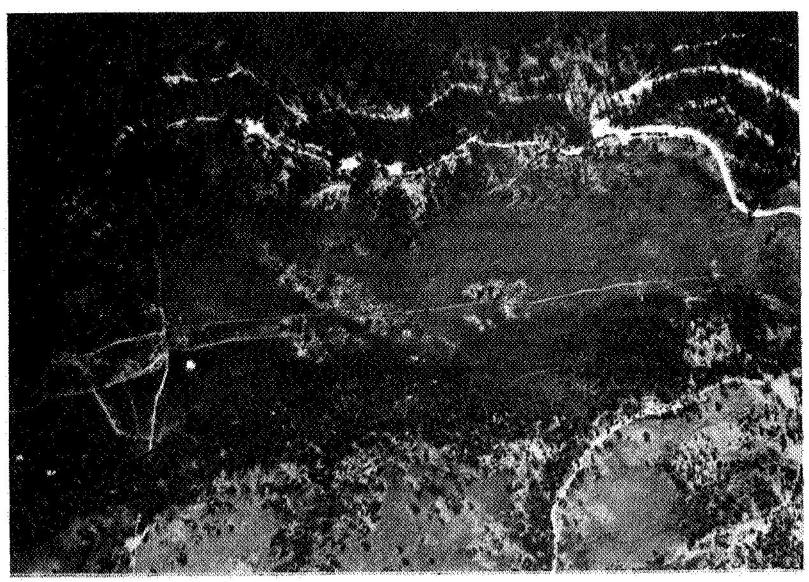


Figure 13. The black-toned area on the left of the photo is a brushfield-conversion unit that has been burned prior to the planting of coniferous seedlings. The presence of such areas is an indication of fairly intensive management practices and suggests the potential for more such activities in nearby brushfields.

single image will provide all the necessary information.

Also illustrated in Figure 8 is a multicolor projection image wherein several black-and-white transparencies are projected in common register, through various colored filters, onto a viewing screen. In this way a composite color image is formed, each terrain type exhibiting aparticular color dependent on its "tone signature" on the black-and-white images. Thus the proper selection of black-and-white images and colored filters will permit the preparation of a true color composite image, a near-duplication of the Ekta Aero Infrared image, or a false-color image which enhances the terrain types of particular interest.

It should be noted that the dependence on tone or color characteristics as discussed above is of particular importance in the interpretation of small scale imagery where fine detail and texture cannot be resolved.

C. The Water Resource

1. Delineation of Watersheds

Certainly one of the most basic operations in terms of watershed management is the delineation of a management unit into watershed units. It is of paramount importance to the hydrologist to know the extent of the watershed for each particular drainage. Only when this is known can management decisions be made concerning manipulation of the environment for purposes of greater quantity, quality or more desirable timing of water yield. Figure 14 illustrates a small watershed that has been delineated on both a topographic map and

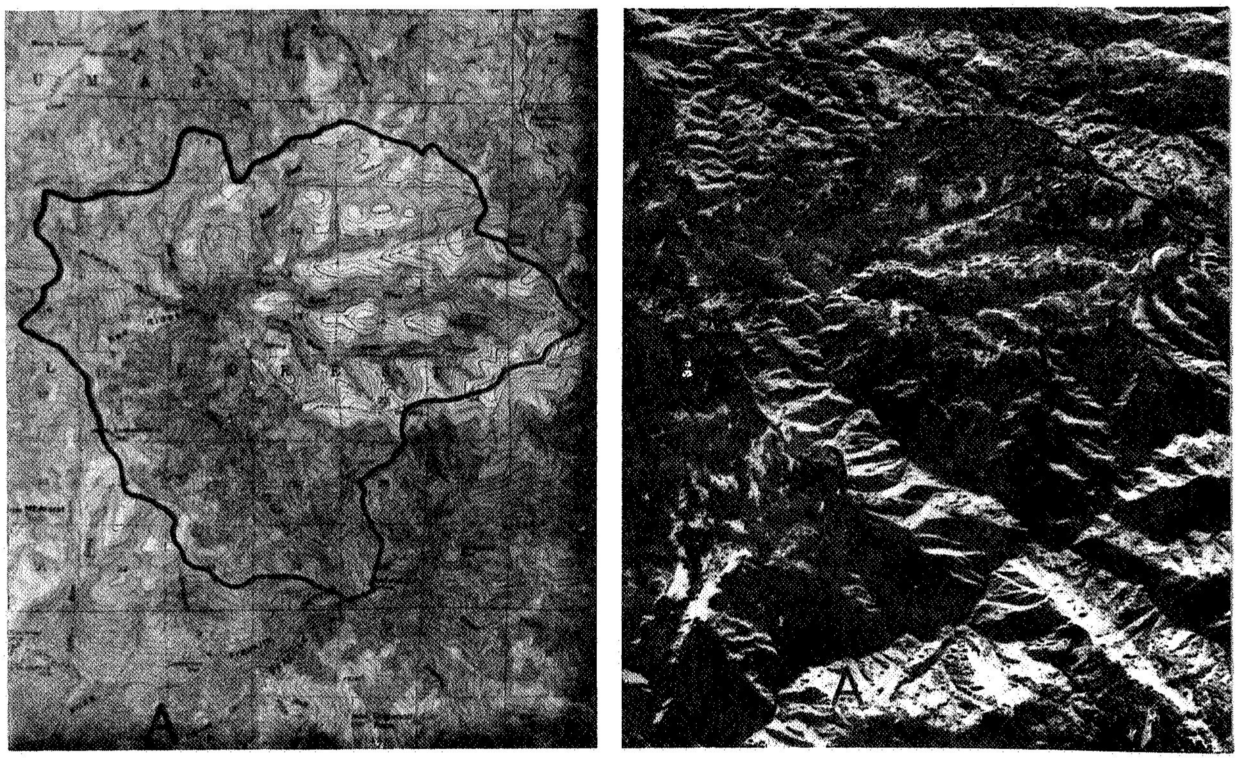


Figure 14: A U.S.G.S. topographic map (left) and a K-land radar image (right) upon which the Bear Creek watershed on the Bucks Lake test site has been delineated. Of particular interest is the degree to which topographic relief is clearly pictured on the radar image, facilitating such delineations. It is also interesting to note that if the aircraft is in the proper position relative to the area of interest, north-facing slopes (see A, above) which are normally in shadow on conventional photography can be illuminated by an active system such as radar.

independently on a radar image of the same area. It was found that radar, due to the fact that topographic relief is emphasized on the image, provided a much easier means of watershed delineation than conventional photos of the same area.

2. Indicators of Available Moisture

Available moisture, both surface and subsurface, is of particular interest to the wildland manager for a variety of reasons. The presence of moisture often is indicative of the capacity of an area to support vegetation crops, be they timber, forage plants or agricultural crops. The availability of water, either from wells, springs or running streams is often the major limiting factor in recreation development. Finally, a knowledge of the location and extent of soil moisture is essential if watershed manipulation procedures are to be undertaken in an attempt to increase stream flow.

It is sometimes possible to directly observe surface moisture differences on conventional photo emulsions, as can be seen on Figure 15. It is also possible to detect differences in subsurface moisture. Figures 16 and 17 illustrate an experiment involving the imaging of a series of soil types which received different wetting treatments, with a thermal infrared camera operating in the 8 to 14 micron thermal band.

Finally, it is often possible to deduce subsurface soil moisture conditions indirectly by drawing inferences from the vegetation that is present. The lower right photo of Figure 22 illustrates the way in which riparian hardwoods and sedges, both indicative of abundant soil moisture, may be identified on Ekta Aero Infrared film. The high infrared reflectance, common to <u>most</u> hydrophytic species,

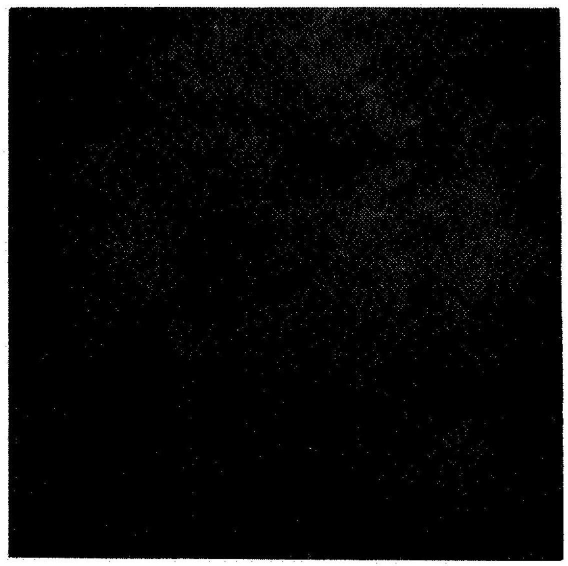


Figure 15: A Gemini photograph of an area near Midland, Texas, illustrating the fact that on space photography obtained at the proper time, soil moisture effects can be observed that would be impossible to discern in their entirety on any standard aerial photography. The dark streak is wet soil as a result of a thundershower. By the time conventional aerial photography of the entire area could be flown, the short-lived surface moisture effects probably would have long since vanished. In this arid region a local storm can greatly increase the growth of grass and also increase its palatability and nutritive value for livestock. Cattlemen can exploit this fact by transporting their animals to such areas.

Davis Sandy Loam	Cornutt Sandy Loam	Black Meadow Loam	Yosemite Sand
Air Dry 3.2	Sprinkled 1 day prev. 10.4	Soaked 1 day prev. 37.0	Soaked 3 days prev. 3.8
Sprinkled 1 day prev. 7.1	Soaked 1 day prev. 19.6	Soaked 3 days prev. 32.6	Air Dry 3.4
Soaked 1 day prev. 16.2	Soaked 3 days prev. 16.2	Air Dry 8.6	Sprinkled 1 day prev. 4.0
Soaked 3 days prev. 9.2	Air Dry 4.1	Sprinkled 1 day prev. 19.5	Soaked 1 day prev. 9.6

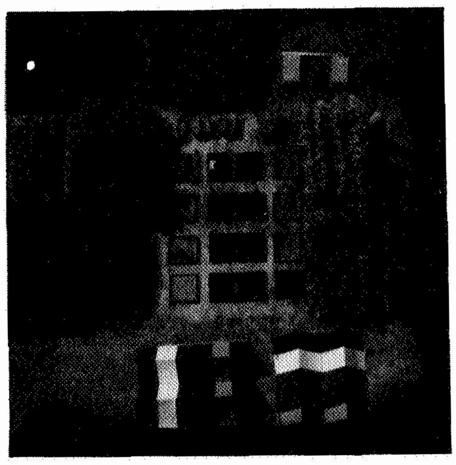
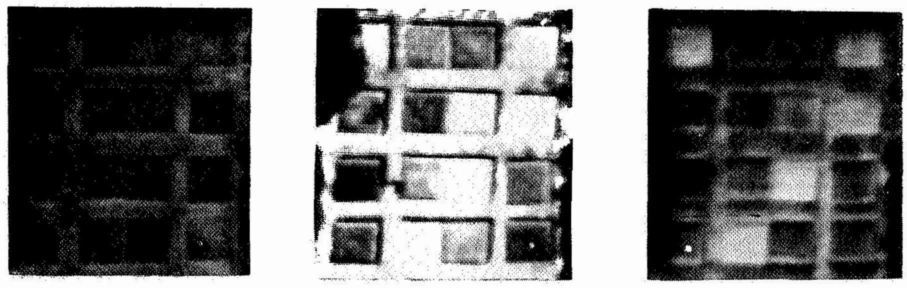


Figure 16: A soil target array which was imaged using a Barnes Thermal Infrared Camera from the catwalk of a tower, 150 feet vertically above the target. See figure 17.



7:00 A.M. 11:00 A.M. 6:00 P.M.

Figure 17: Three thermograms taken of the soil moisture target array from the catwalk of the Davis water tower, 150 feet above the target. The wavelength sensitivity of the Barnes Thermal Infrared Camera used in this experiment was from 8 to 14 microns. Figure 16 describes the soil types and treatment involved, and the soil moisture percents as measured by a surface soil moisture meter. Note that at midday the soils with lowest moisture content appear light in tone, indicating a higher temperature than the darker-appearing soils that have higher moisture contents. Sequential thermal infrared imagery can trace the rate of drying of soils, thereby indicating when moisture conditions are most favorable for planting and also when crops should be irrigated.

results in a bright pink color on this film, enabling the interpreter to discriminate them from dry-site vegetation, even on small scale photography of poor resolution.

3. Reservoir Volume

A study was carried out at Bucks Lake, a Pacific Gas and Electric Company reservoir, to determine the extent to which it was possible to determine reservoir volume on small scale aerial imagery. The photograph in Figure 18 has been annotated to illustrate the points from which measurements were made. These measurements are tabulated in Table 2 as measured on sequential imagery of the Lake, and graphically compared with lake surface elevation data supplied by the reservoir administrators.

"Ratio X" is the distance on the photograph that the lake subtends on a line from A to a, divided (and thus adjusted for scale differences on photos of different dates) by the photo distance from point 1 to point 2. "Ratio Y" is a measurement from a land feature (B) down to the water's edge, again corrected for scale. Thus, as lake volume increases, we would expect Ratio Y to decrease, whereas Ratio X would increase.

If the shoreline along lines A and B were of a constant slope, one would expect a linear relationship between reservoir surface elevation and the measured distances. As can be seen in Figure 19, some irregularities do occur which can be attributed to either an uneven shore slope or inprecise photo measurements. But certainly the data do suggest the feasibility of measuring reservoir volume in the manner tested. An initial calibration of a reservoir is required which could relate at least two reservoir elevations (which

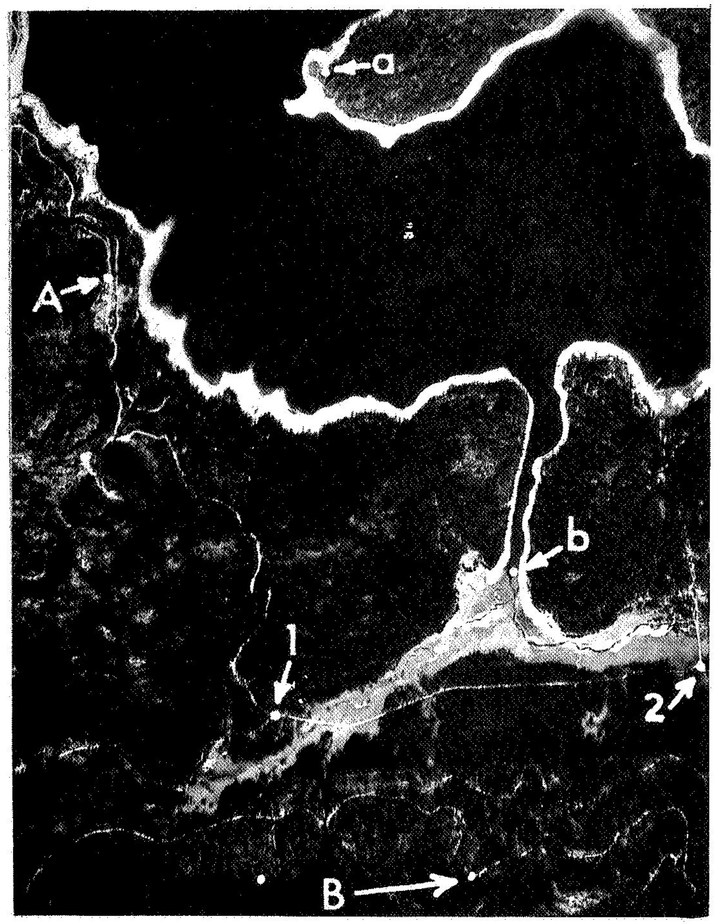


Figure 18: A small scale panchromatic photograph showing points used in measurements designed to determine reservoir volume on aerial photography. For explanation, see text.

RATIO X				RATIO Y			
Date	Photo Ratio	Elevation Above Sea Level (ft)	Lake Vol. (acre ft)	Date	Photo Ratio	Elevation Above Sea Level (ft)	Lake Vol. (acre ft)
6-65	.5385	5150.8	95,336	6-65	.5318	5150.8	94,336
9-65	.4868	5123.8	50,814	9-65	.6711	5123.8	50,814
6-66	.5166	5141.1	77,715	6-66	.5563	5141.1	77,715
9-66	.5073	5123.9	50,957	9-66	.6213	5123.9	50,957
6-67	.5428	5156.6	104,867	6-67	.5137	5156.6	104,867

Table 2. Data showing sequential lake volume, elevation and photo distance on aerial photography of Bucks Lake. For explanation, see text.

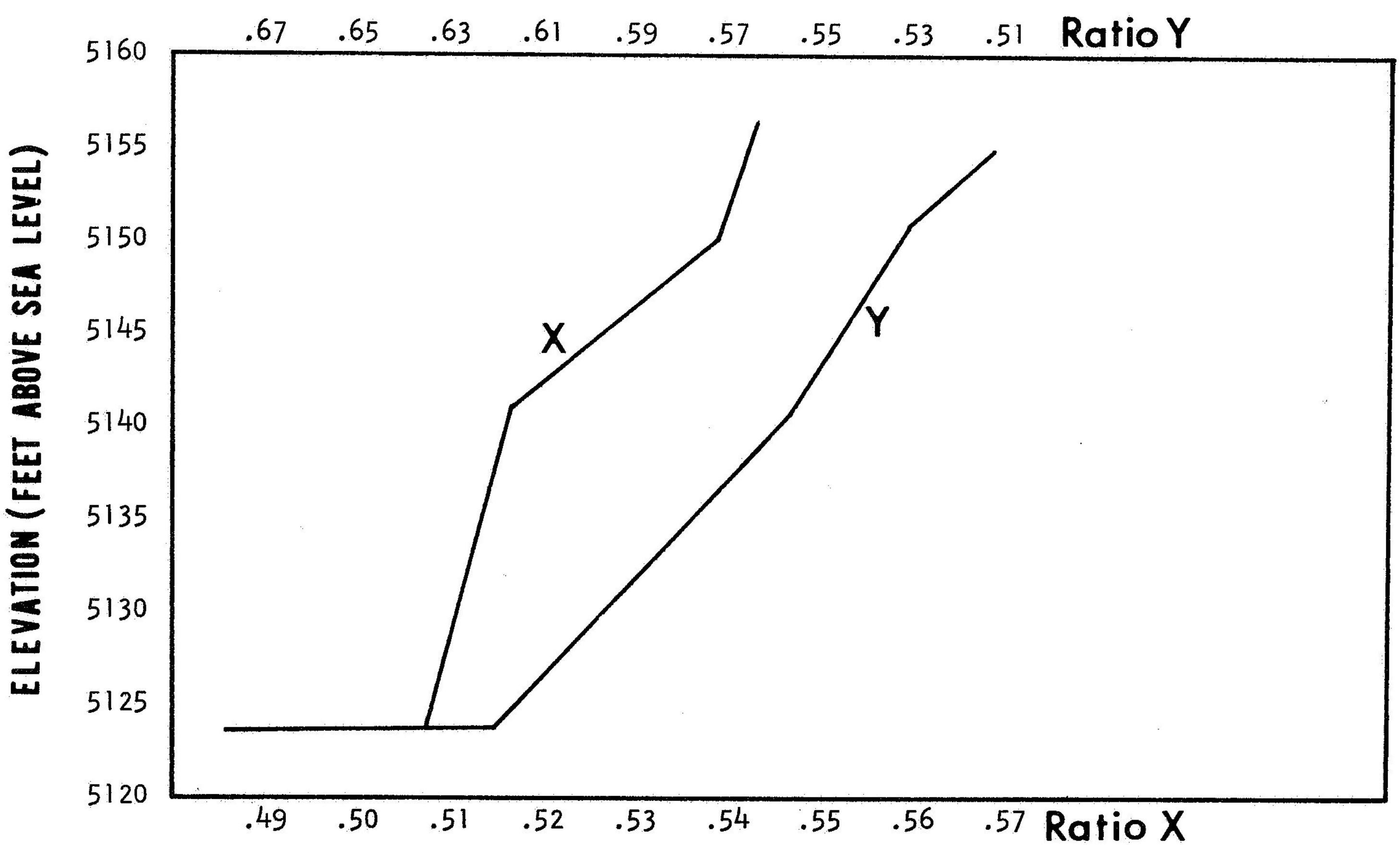


Fig 19. Relationship of lake elevation to two photo distances measured on photography of Bucks Lake. For explanation see text.

can in turn be related to volume) to photo measurements, and all subsequent measurements need only to be made on the images.

4. Snow Measurements

The most common use of aerial photographs in snow measurements involves the use of snow depth markers (see Figure 20) which are set up at selected points within a watershed, and observed periodically from the air either visually or by means of aerial photos. However, small scale imagery may be put to many additional uses by the hydrologist who is interested in snow accumulation and melt rates. Figure 22 illustrates two areas within the Bucks Lake test site that were photographed using Ekta Aero Infrared film at nearly the same date during successive years. It is of course evident that snow pack distributions can be easily discerned, even on relatively poor quality small scale imagery. However, other information may be derived of even greater importance to the wildland manager contemplating taking specific steps to manipulate the environment in order to enhance the value of the watershed. Vegetation mapping was discussed in a previous section. If vegetation mapping is performed in conjunction with mapping of snowpack distribution, it is often possible to derive valuable information as to the relationships between vegetation type and snow retention. The top photos in Figure 22, for example, indicate that snow retention is poor in both very open brushfields or dense timber stands, but is greatest in open timber stands or small openings, where heat is readily radiated upward, but there are still enough trees to provide shade during daylight hours. The bottom photos in Figure 22 demonstrate

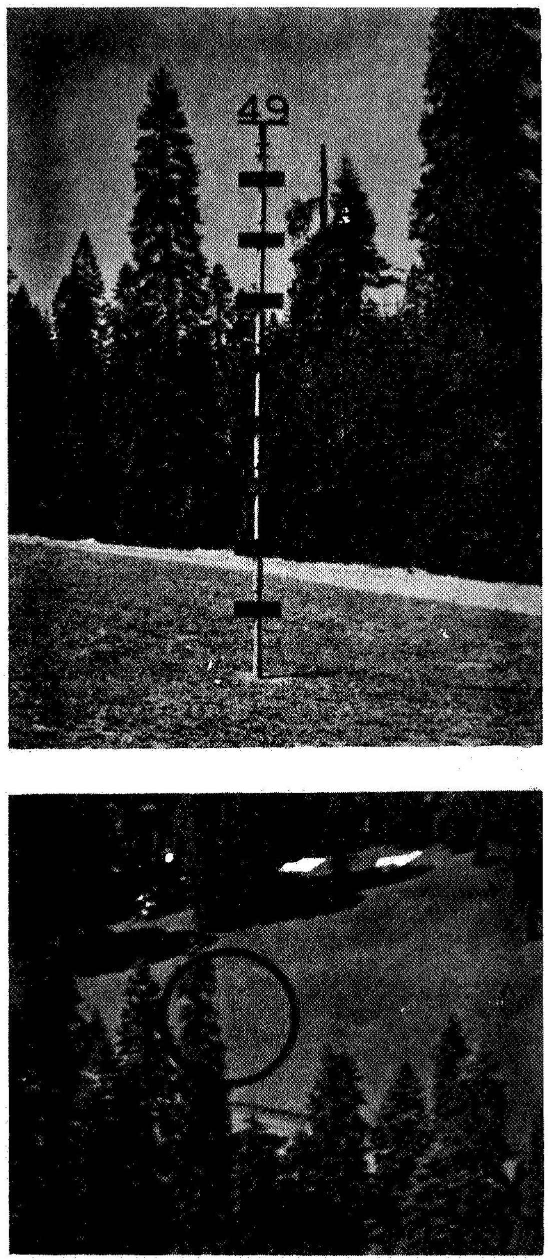
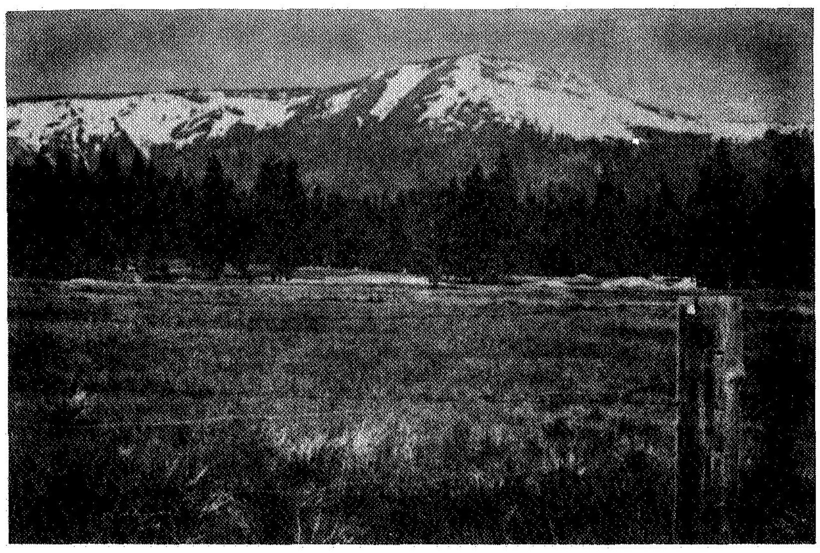


Figure 20: Snow-depth markers strategically placed make possible a determination of depth of snow pack during the winter, when many wildlands are totally inaccessible except by air. Often a careful inspection of sequential small scale photography will facilitate the placement of such markers where they will yield the most meaningful data.



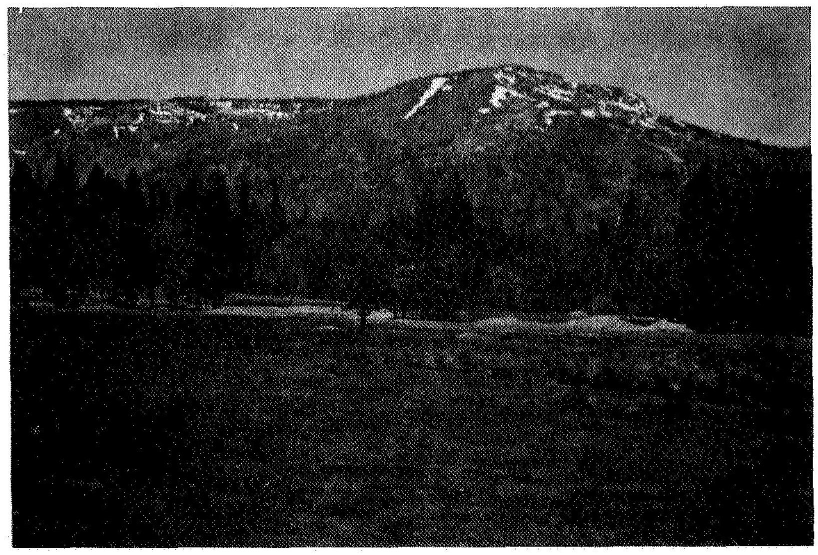
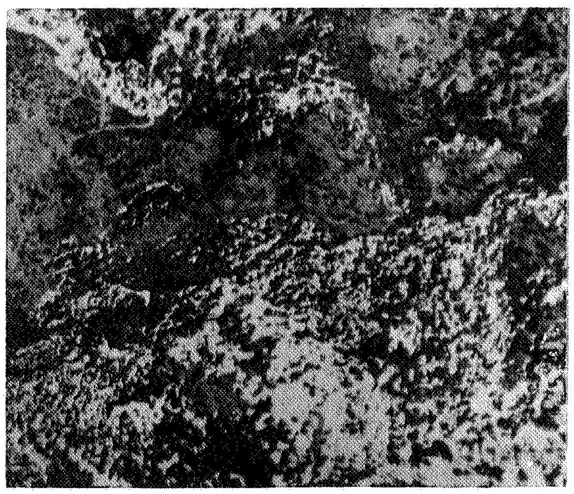


Figure 21. The top photo of Spanish Peak, in the Bucks Lake Test Area was taken on June 4, 1965. The lower photo was taken on the same date in 1966. Such sequential imagery, preferably obtained from the air can indicate to the trained watershed manager the amount of runoff that can be expected at later dates in the dry summer season.

June 9, 1965
Snow clearly seen in open areas.

June 11, 1966
Little snow remains in open areas.



June 9, 1965
This area is nearly 50% snow-covered.

June 11, 1966
Same area devoid of snow.

Figure 22. Sequential small scale imagery as illustrated above can serve as a valuable guide to hydrologists in their determinations of both surface and subsurface runoff that can be expected during a particular period. In addition, such imagery is valuable in the study of topographic and vegetation effects on snow retention and melt patterns, and may be of great help in planning management procedures designed to improve quantity and/or quality of runoff.

readily the relationship between aspect and snow melt. The snow covered area to the bottom of the 1965 photo is a north-facing slope, whereas the middle clear area is south-facing and the upper snow covered area faces north. These relationships are often helpful in deducing slope and aspect on non-stereo imagery. From a study of such imagery, the hydrologist might well gain clues as to where, for example, timber thinning procedures would be best carried out in order to increase snow retention.

D. The Edaphic Resource

1. Geologic and Soils Mapping

In this discussion, the soil and geologic resources are combined into a common category due to the fact that it is difficult, if not impossible to deal with one without including consideration of the other. It is recognized that one of the most important factors affecting soil type and development is the underlying geology. Although he cannot see this underlying geology directly, the image interpreter often can make inferences as to geology by examining the overlying soil and vegetation. In many areas covered with relatively dense vegetation, soils are hidden from view to the aerial observer, and so inferences must be drawn using a knowledge of soil-vegetation relationships. In such instances, double inferences may be used to deduce the subsurface geology, of an area, i.e., the soil type is deduced from the vegetation and the subsurface geology is then deduced from its associated soil type.

In the Bucks Lake Test site there is a high correlation between timber volume on undisturbed sites and soil type. Dubakella soils, associated with underlying serpentine rock, nearly always support a sparse timber stand, whereas the adjacent Cohassett soil, derived from andesitic tuff, supports timber stands with much higher volumes. In addition, the most common species found on the dubakella soil are Jeffrey Pine (Pinus jeffreyi), Incense Cedar (Libocedrus decurrens), and Wedgeleaf Ceanothus (Ceanothus cuneatus), whereas the Cohassett soil is generally associated with Ponderos Pine (Pinus ponderosa), Sugar Pine (Pinus lambertiana), White Fir (Abies concolor), and Douglas-Fir (Pseudotsuga menziesii). Thus a detailed knowledge of soil-vegetation relationships may enable the interpreter to produce accurate soil maps without ever directly observing the soil and even to infer the presence of subsurface rocks, such as the serpentine rocks beneath a dubakella soil.

In areas where soil is exposed to the vertical view, soil tones or colors are often valuable clues to an identification of that soil. Figure 23 illustrates reflectance curves for a number of soils found in the Bucks Lake Test Site. The wide variation in reflectances from these soils, resulting in different "tone signatures" on multispectral imagery often facilitates the identification of such soils purely on the basis of tone or color.

2. Evaluation of Geomorphology

The wide synoptic view afforded by imagery obtained from earth orbit is particularly valuable in the evaluation of geomorphology, or landforms, which often cannot be seen in their entirety on images

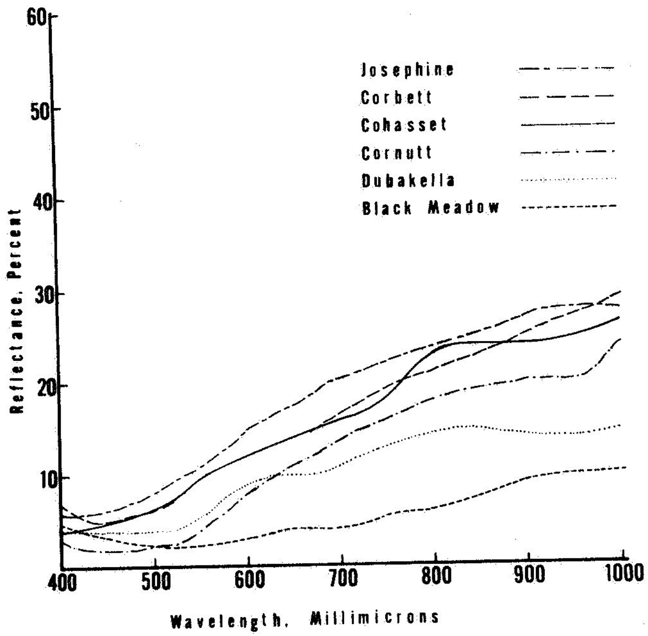


Figure 23. Reflectance curves for a number of soils found in the Bucks Lake Test Site. The wide range of reflectances often makes possible an identification of soils on aerial imagery wholly on the basis of tone or color.

obtained from conventional altitudes. Figure 24 illustrates the degree to which gross landforms can be mapped using existing Gemini photographs, in some cases more accurately than had been done using conventional ground mapping methods.

The proper choice of image type can, in many cases, enhance the accuracy of interpretation of landforms on small scale imagery. Figure 25 is a K-band radar image of a large portion of the Bucks Lake test site (a ground distance of approximately 12 miles is covered from the top to the bottom of the image). The "shadows" caused by the difference in angle between the line of signal from the aircraft and the varying slopes in the scene tend to accentuate the topography, thus facilitating interpretation of gross landforms. Another interesting example of the utility of specific sensor types for evaluating geomorphology is illustrated in Figure 26. Thermal infrared photographs in the 8-14 micron band were taken of a geothermal area in Lassen Volcanic National Park using a Barnes Model T-4 Infrared camera. It was possible to detect hot vents and fumaroles on the thermal imagery that were entirely undetectable on conventional photographs. The presence of such geothermal activity is of particular interest to trained geologists in their inventigations as to the geomorphology of a particular area. In addition, such areas represent potential sites for electrical power generating plants wherein vents are capped, and steam pressure is used to activate generating turbines.

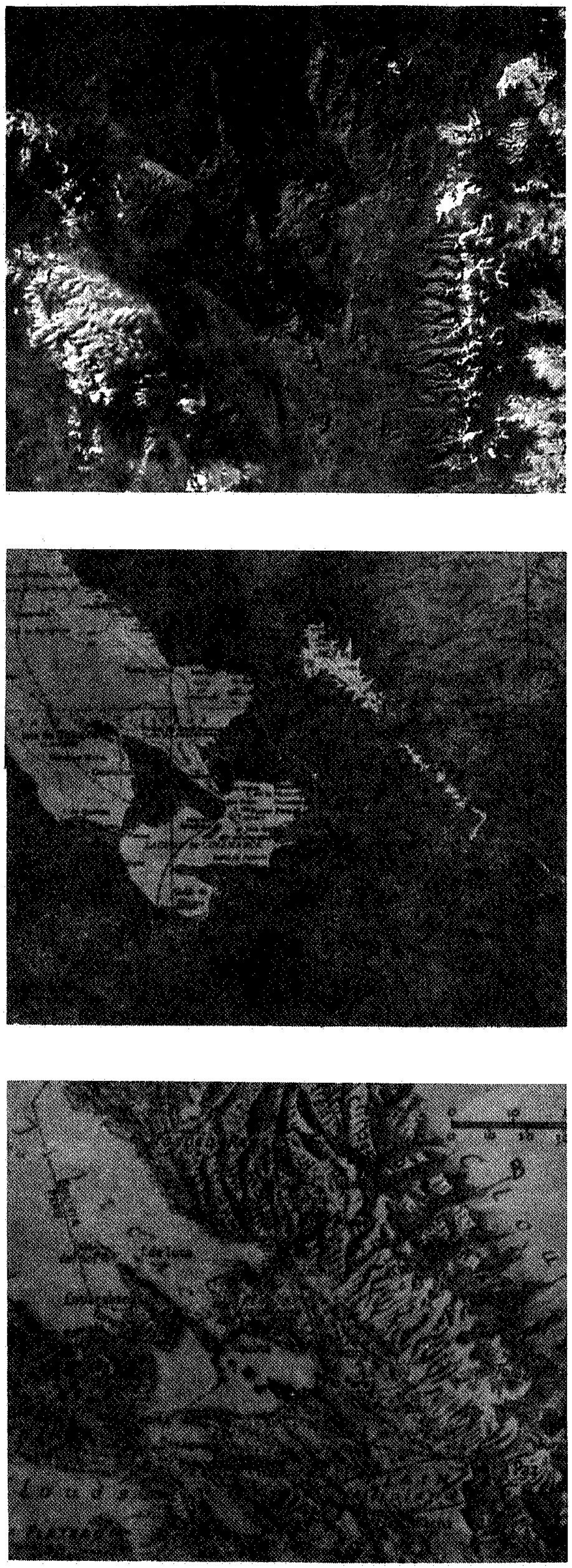


Figure 24. The top photo was taken by Gemini astronauts of the Lake Titicaca area of Bolivia. The middle photo is a copy of one of the best maps of the area available prior to acquisition of the space photography, and at the bottom is seen a map of the same area drawn using only the space photo as a guide. Improvements in the accuracy of mapping the location of islands, shoreline configuration and gross topography are apparent. A field check of this same area would have entailed several man-months of effort and the expenditure of large sums of money to produce a map of the same accuracy as was produced in a few days with the use of the photograph. (Photo examples from Earth Resource Surveys from Spacecraft, U.S. Army Corps of Engineers, for Earth Resources Survey Program, NASA, Dr. Erwin Raisz, Contributor).

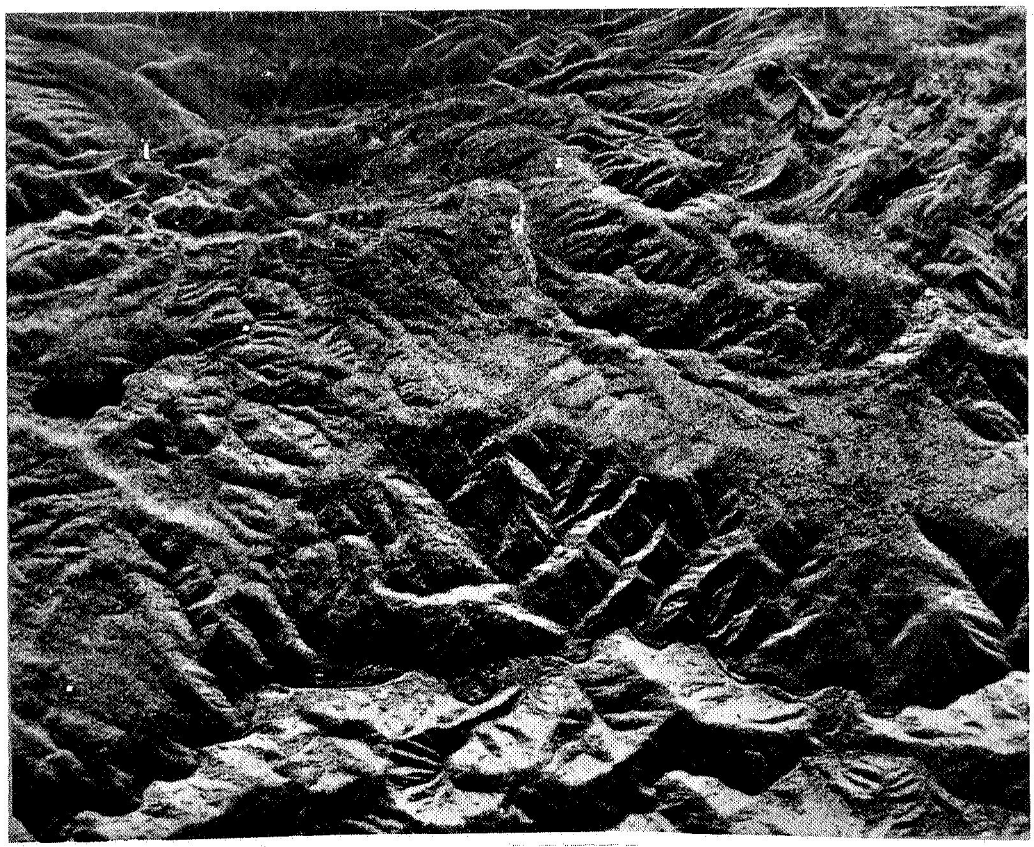
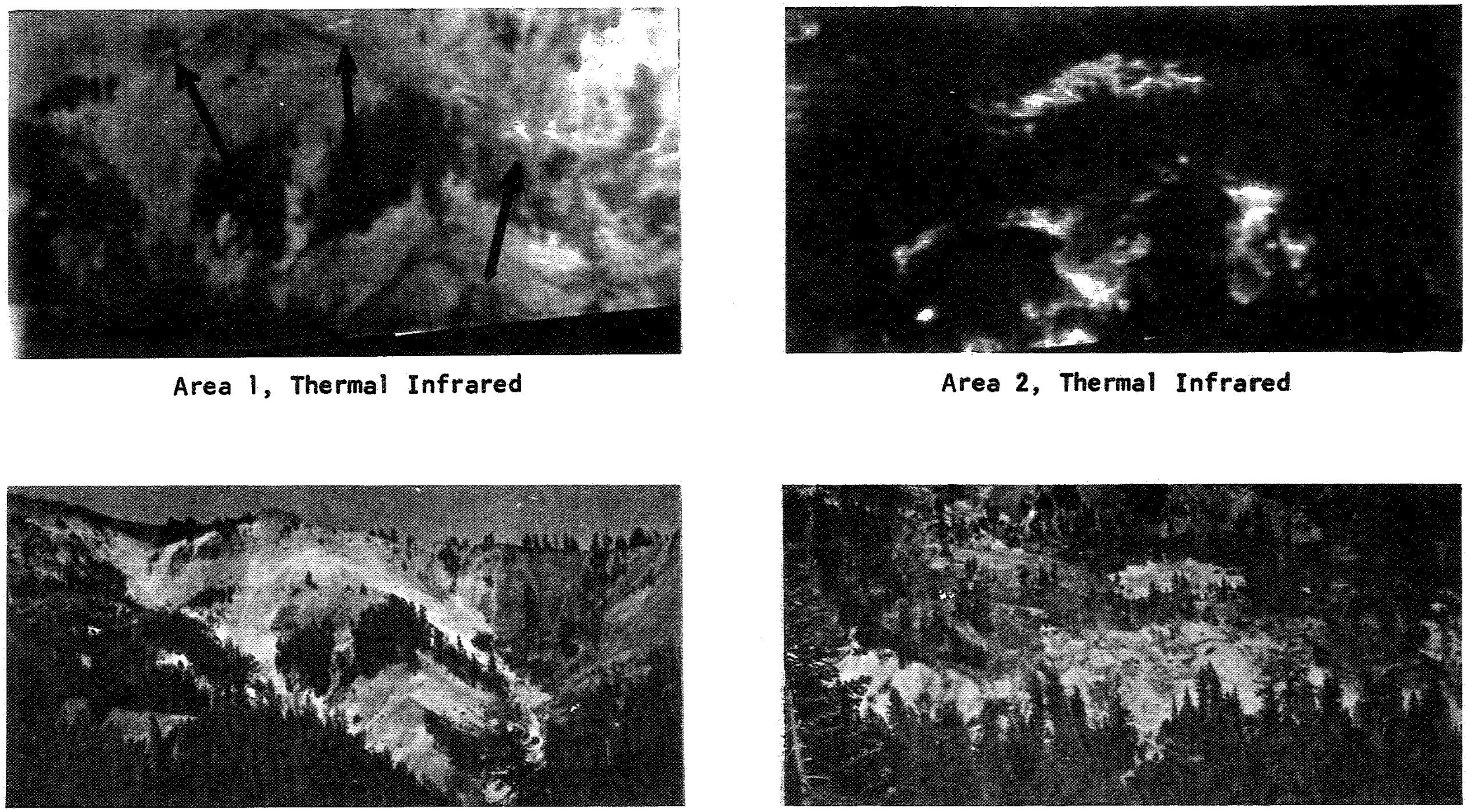


Figure 25. A K-band radar image of the Bucks Lake Test Site. The "shadows" seen here are characteristic of such radar images and greatly facilitate the interpretation of gross land forms by accentuating the topography.



Area 1, Thermal Infrared

Area 2, Thermal Infrared

Area 1, Ektachrome

Area 2, Ektachrome

Figure 26. Thermal infrared images utilizing the 8 to 14 micron band of the spectrum (top), and conventional color photographs (bottom) of two different geothermal areas in Lassen Volcanic National Park in California. The light toned areas on the thermal images indicate regions of geothermal activity. Such regions are a potential site for power-generating installations and are indicative, to a trained geologist, of the underlying geologic formations.

E. The Wildlife Resource

Applications of remote sensing to wildlife management are logically divided into two categories: (1) population inventories, and (2) habitat evaluation.

For purposes of population inventories, very small scale imagery has only limited application due to the fact that a ground resolution of a foot or two is necessary for detection of most wildlife. Large scale photography has proven operationally valuable for the inventory of domestic livestock (see "The Inventory of Livestock and Crops by Means of Aerial Photography", Statistical Reporting Service, USDA, School of Forestry, University of California, September, 1966) and such imagery has shown promise of being useful for inventories of wildlife as well. Considerable research is usually needed to determine the optimum image type, time of day and season of year to obtain imagery for the particular species in question, as the optimum specifications vary depending on the color and habits of the animal and the type of environment in which it is generally found.

Probably the greatest use of small scale imagery in wildlife management lies in the field of habitat evaluation, and as such is closely allied with the applications in vegetation and soils mapping, as discussed earlier. Generally, the techniques of vegetation and soil delineation and classification are similar whether the purpose is for timber or wildlife management. The difference lies in the criteria used when delineating particular types on the imagery and the implications derived from the findings.

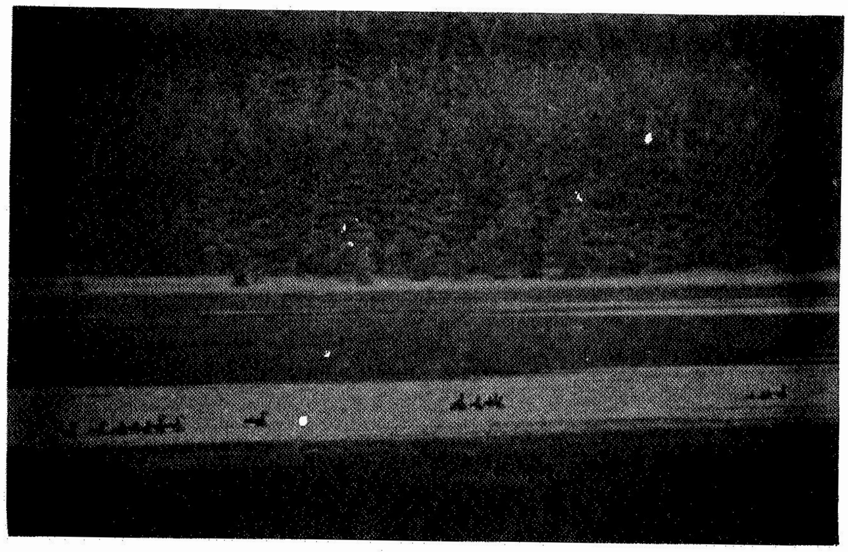


Figure 27. An Ekta Aero Infrared aerial photo (above) and a Kodachrome ground photo (below) of Snake Lake near Meadow Valley, California. The unique pink appearance of aquatic vegetation on the aerial photo would suggest to the wildlife manager the presence of an ideal habitat for migratory water-fowl, such as Canadian Geese. The ground photo shows that such conclusions are indeed valid.

V. Results and Conclusions

In discussing the optimum image type or combination of types for the evaluation of wildland resources, and the spatial resolution necessary to perform such an evaluation, it must be remembered that optimum specifications vary with the particular resource involved, and the intensity of resource management to be practiced. For these reasons, and the fact that this study has not dealt in detail with all of the resources involved, the recommendations that follow should be considered to be general and preliminary; operational specifications can be recommended only after specific goals of a survey have been defined.

For purposes of gross vegetation mapping it has been found that some information can be derived with very low resolution systems, such as existing Gemini photography. Many portions of the world can, in fact, be mapped more accurately on such imagery than they are at the present time, and so for very gross mapping of undeveloped areas such imagery might yield a great deal of information to the wildland manager. On the other hand, such detailed information as timber volumes and species composition can only be extracted if the imagery is of relatively high resolution (ground resolution of perhaps 5-10 feet). These figures do not, however, adequately express the potential of small scale imagery obtained from orbiting vehicles, for certain other purposes. For example, when it is possible to employ both limited on-the-ground checks, and two-or three-stage sampling with systems of higher resolution than that obtained with the primary spaceborne sensors, the useful information that can be derived from small-scale earth-orbital imagery may be greatly increased. Specifically, the small scale imagery can be interpreted and obvious types delineated; however, an identification of these types in terms of quantitative data can be deferred until limited sampling, either on the ground or with high resolution systems, indicates the implications of the initial gross findings.

The one image type tested in this research that provided the most information for most purposes concerning vegetation was that obtained using Ekta Aero Infrared film. The infrared sensitivity generally results in a better contrast between vegetation types, and also results in less atmospheric attenuation than most other photographic emulsions. Color enhancement procedures using several multispectral black-and-white images have also proved promising. Using this method, black-and-white images which can be telemetered to earth from orbiting vehicles can be combined to form color images analogous to Ektachrome or Ekta Aero Infrared photographs. They also can be used to form false color composites that will enhance special items of interest.

For purposes of geologic or soils mapping, resolution necessary to provide sufficient information for identification is generally lower than that necessary for vegetation mapping, as greater dependence can usually be put on tone or color values rather than on texture and detail. Generally speaking, a multispectral sensor producing imagery suitable for color enhancement would seem to be optimum; however, radar systems produce images very helpful in the interpretation of topography and landforms, and also provide a day-and-night, all-weather capability.

Insufficient data have been collected to allow the specification of an optimum sensor for purposes of water resource management. Thermal infrared images have proven promising for detection and mapping of ground water and determination of soil moisture content. Conventional Aerial Ektachrome film seems sufficient for the mapping of snowpacks, although black-and-white infrared film or Ekta Aero Infrared film will provide nearly as good results and with the added advantage of enhancing the interpretation of lush riparian species as well as areas of standing water.

It can be concluded that the research performed to date has demonstrated that the acquisition of small scale imagery, either by conventional means or from vehicles in earth orbit can provide the wildland manager with valuable information necessary for the intelligent management of natural resources occurring in wild areas. Probably the most useful application of such techniques are found in previously undeveloped areas where the existing information is either insufficient or lacking, and where limited accessibility or vastness of area precludes a thorough inventory and evaluation of the resources by conventional means. Probably the most advantageous studies that can be carried out at this time should concern themselves with the capability of specific sensors for specific applications, with the emphasis on the value of quantitative data extracted. Only after such studies are accomplished can adequate evaluations of the economic advantages of remote sensing from earth orbital vehicles be fully made.

APPENDIX

A SAMPLE PHOTO INTERPRETATION GUIDE

A PHOTO INTERPRETATION GUIDE TO VEGETATION CATEGORIES IN THE BUCKS LAKE TEST SITE

This appendix is intended to be a sample photo interpretation guide of the type that might well be used in the training of interpreters of small scale imagery of wildland areas. This example concentrates on the vegetation resource, with particular emphasis on vegetation types of importance to the timber manager. It consists of (1) a photo interpretation key dependent only on percent crown closure (the % of the area covered by vegetation as seen in the vertical view, (2) a graphical description of those areas containing some timber, and (3) a photo example of each category with a written description of the category, its timber management implications, and the identifying characteristics exhibited by it on imagery flown to optimum specifications.

KEY TO TIMBER CATEGORIES

A. Total vegetative cover 0 - 20% . . . . Type I

AA. Total vegetative cover 20 - 50% . . . . Type II

AAA. Total vegetative cover 50 -100%

  B. 0 - 5% Total cover due to commercial conifers

    C. Total vegetative cover 50 - 80% . . . . . Type IIIa

    CC. Total vegetative cover 80 - 100% . . . . . Type IIIb

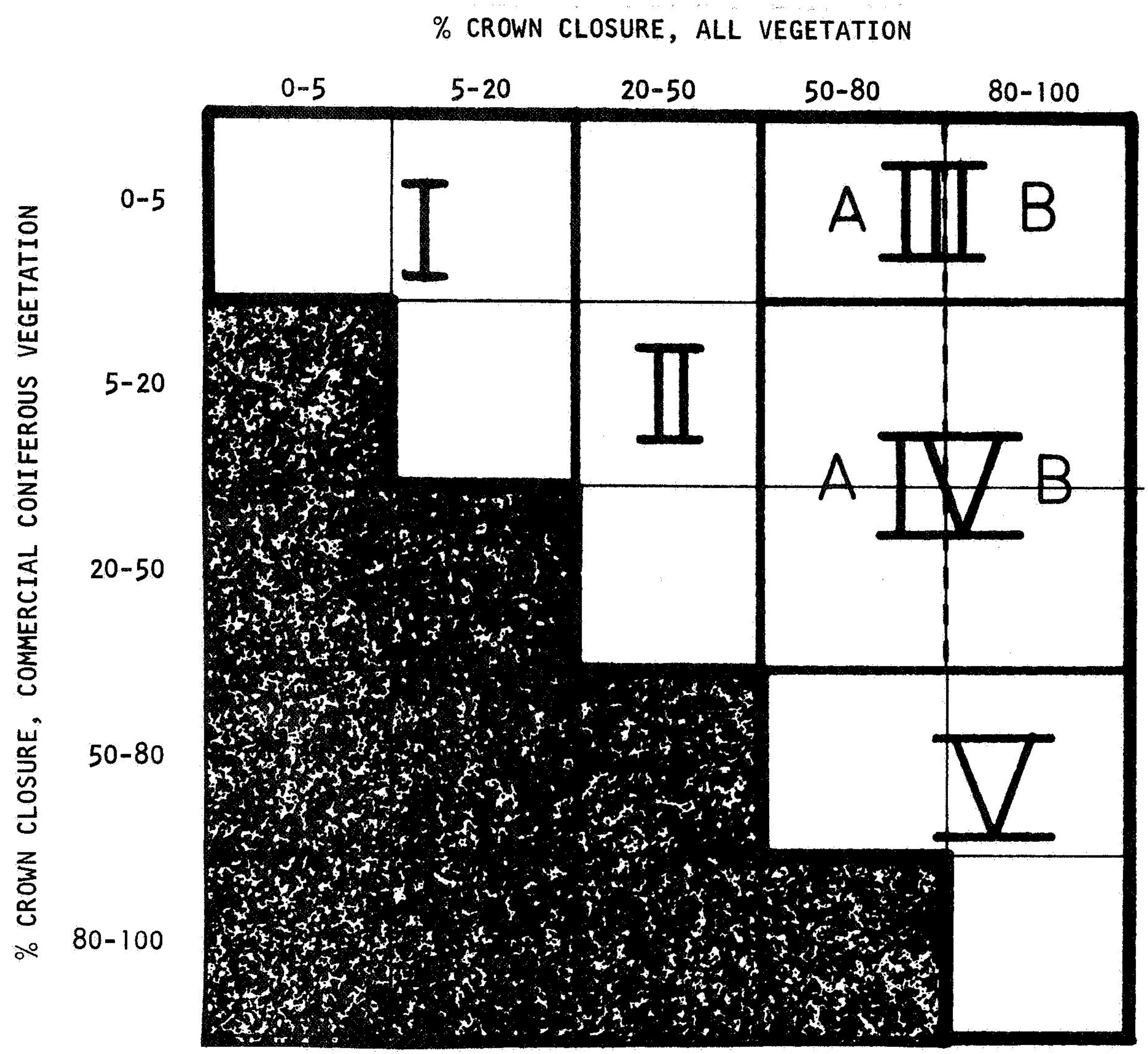
  BB. 5 - 50% Total cover due to commercial conifers

    C. Total vegetative cover 50 - 80% . . . . . Type IVa

    CC. Total vegetative cover 80 - 100% . . . . . .Type IVb

  BBB. 50 - 100% Total cover due to commercial conifers.Type V

Note: "Total cover due to commercial conifers" means the percent of the area covered by commercial conifers (even if all other vegetation were removed). It does not mean the percent of the vegetation that is commercial conifer. It is not within the scope of this Appendix to present a key to <u>non</u>-timber categories. However, three such categories are illustrated and discussed in the concluding three pages of the Appendix.



Timber Categories Defined

I: Very little vegetative cover of any type.

II: Limited vegetative cover, may be wholly or partly due to commercial coniferous vegetation.

IIIa: Moderate vegetative cover, very little of which is commercial coniferous vegetation.

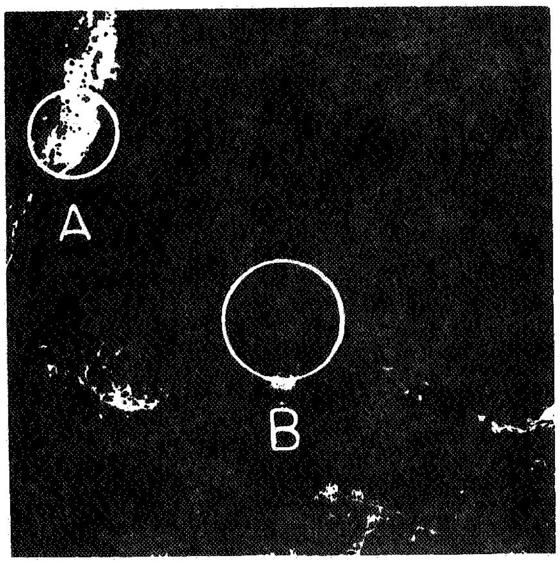
IIIb: Heavy vegetative cover, very little of which is commercial coniferous vegetation.

IVa: Moderate vegetative cover composed partially of commercial coniferous vegetation.

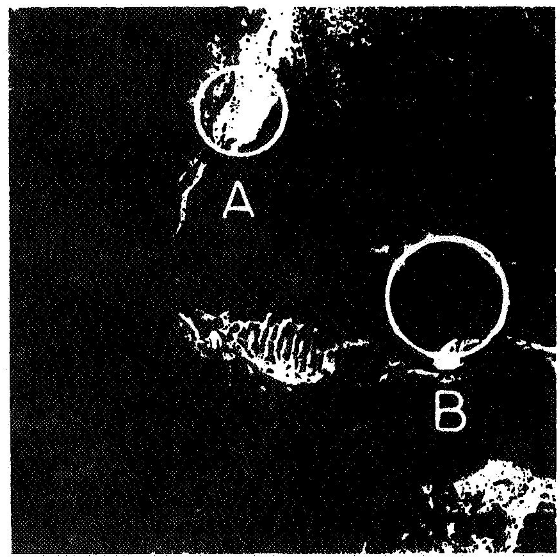
IVb: Heavy vegetative cover composed partially of commercial coniferous vegetation.

V: Moderate to heavy vegetative cover composed mainly of commercial coniferous vegetation.

Note: Commercial conifers--ponderosa pine, sugar pine, Jeffrey pine, white fir, red fir, incense cedar and Douglas fir--are those trees with a dbh of greater than 10 in. They may be recognized on aerial photos by their coarse texture and relatively larger crown diameter.



Aerial Ektachrome Film



Ekta Aero Infrared Film

Timber Category I

The light tone exhibited by this category (A above) on both Ekta Aero Infrared and Ektachrome films is the major factor which facilitates its identification. The almost complete lack of any vegetative cover allows the bare ground (rock or soil) to stand out in contrast to surrounding darker toned areas covered by forbs, brush and trees. Comparison with a nearby dirt road may help the interpreter in deciding whether a particular light toned area is bare rock or a soil surface. There is, however, the chance of confusing a barren area with dry stubble or a mown field.

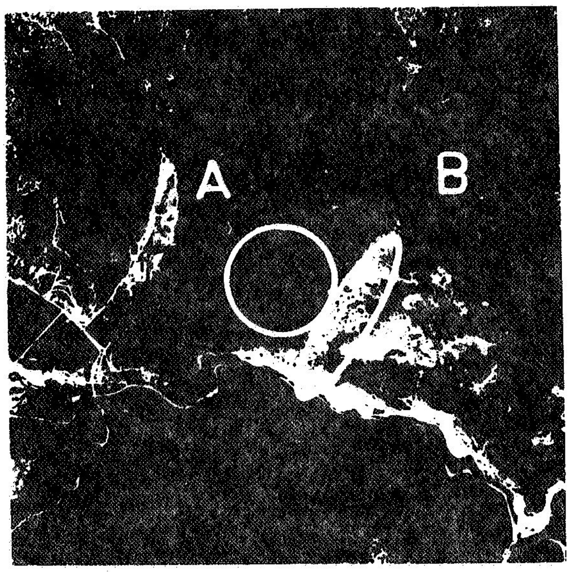
It is of great importance for a wildland manager to have an accurate inventory of unproductive land. He can then determine if there are any steps which may be taken to establish a vegetative cover. For example, a cleared area might be capable of supporting seeded grasses or soil-building brush species, thus eventually supporting a productive forage crop and contributing more and/or better quality water to the watershed. Aerial photos also provide a means of observing which areas may be treated first. Among the many factors often indicated by up-to-date imagery are: extent of land to be reclaimed, problems in protecting high valued lands nearby, possibilities for preservation of aesthetic appeal, means for improving accessibility to important areas and proximity of such areas to other current or proposed forest operations. Likewise, the location, amount and nature of truly "waste" land areas should be taken into account in arriving at and implementing management decisions.

Aerial Ektachrome Film

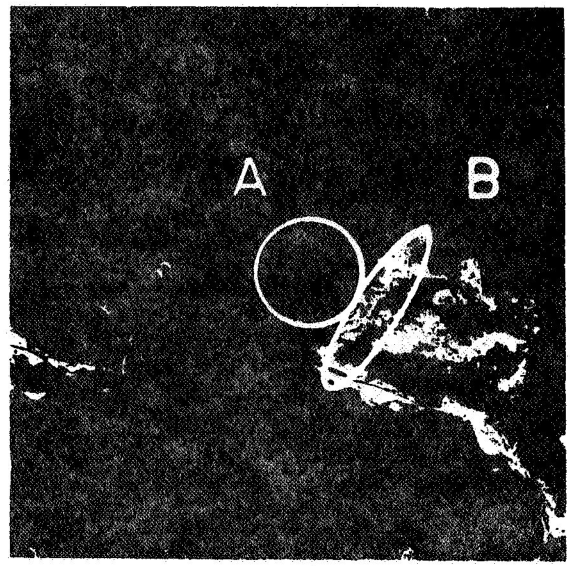
Timber Category II

The vegetation in this category can be clearly seen due to its darker tone which stands out in a polka-dot pattern against the larger amount of light-toned, barren background. It should be obvious that less than one-half the area is taken up by this dark covering. By noting tonal shades, texture, shadows and comparing with surrounding vegetation, the presence or absence of commercial (greater than ten inches dbh) conifers may be ascertained and a relative estimate of its overall cover made.

The importance of this timber category lies in possible improvement of its productive capacity. The fact that some vegetation now exists indicates a certain capacity for the site to support vegetative growth. A forest manager may further determine that present conditions are due to recent logging, past fires or more destructive activities such as hydraulic mining. This deduced knowledge would then help suggest which areas offer greatest promise of improvement.



Aerial Ektachrome Film



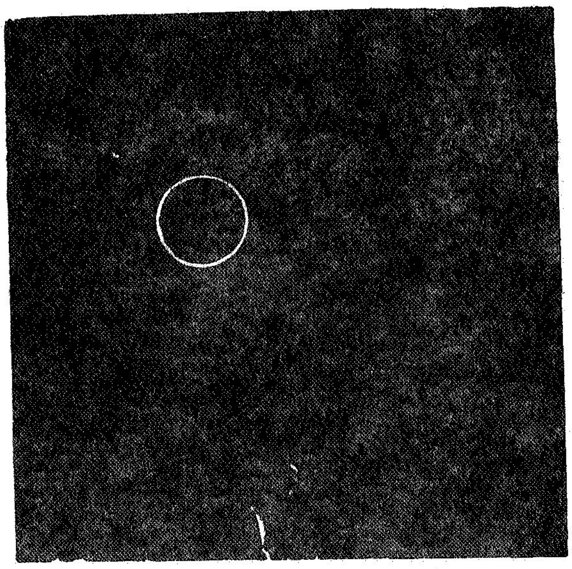
Ekta Aero Infrared Film

Timber Category IIIa

It is obvious, due to the dense texture and dark image tone, that plot A has abundant vegetative cover, certainly more than fifty percent. It is interesting to compare the ground estimation with the aerial view of the stand; the ground shot shows that at least twenty percent of the area is open.

By convergence of evidence (such as comparison of crown size and texture with stands a mile or so away, numerous straight skid trails meeting at a common point at the top of the hill, and the tight growth found between these lines), an experienced forester may conclude that this area had been cable logged. Indeed, this is true and it explains why even with the dense vegetation there is not yet a significant cover of commercial sized conifers in the remaining second growth stand.

The management implications for areas of this sort lie in decisions to apply timber stand improvement efforts in order to upgrade the output of timber on a site that is readily capable of supporting dense vegetation. Conversely, if a forester lacked inventory knowledge of the expanse of land which would fall into this category, opportunity for successful management might be critically affected.

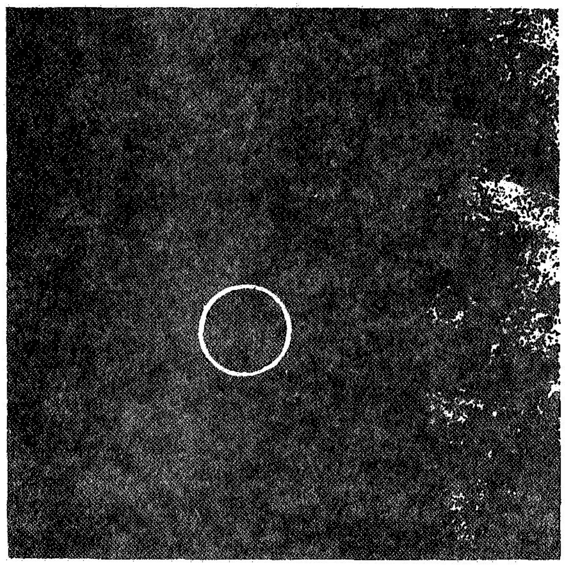


Aerial Ektachrome Film

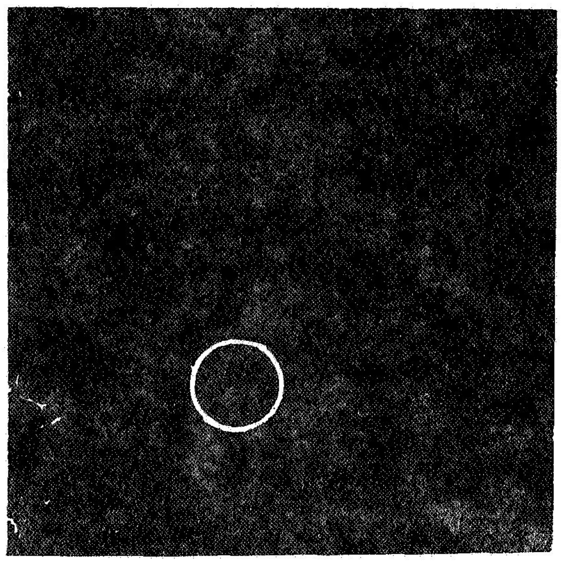
Ekta Aero Infrared Film

Timber Category IIb

This stand appears very dense both as seen on the ground and as seen on the aerial photo. The large number of trees and their even, moderate texture help indicate that although the stand is well stocked there are really very few large trees present. Understory brush and heavy coniferous reproduction add to the total vegetative cover, but most of the trees are only of pole size. Such stands obviously contain little large commercial timber, but since they have high vigor, it may well be a worthy investment to thin and prune them. Since the trees have overtopped the understory brush, there is added growing space for them which should permit both accelerated growth and the production of very valuable knot-free wood on clear butt logs. Through this knowledge, a more valuable crop with a shorter growth cycle may be encouraged with proper management techniques.



Aerial Ektachrome Film

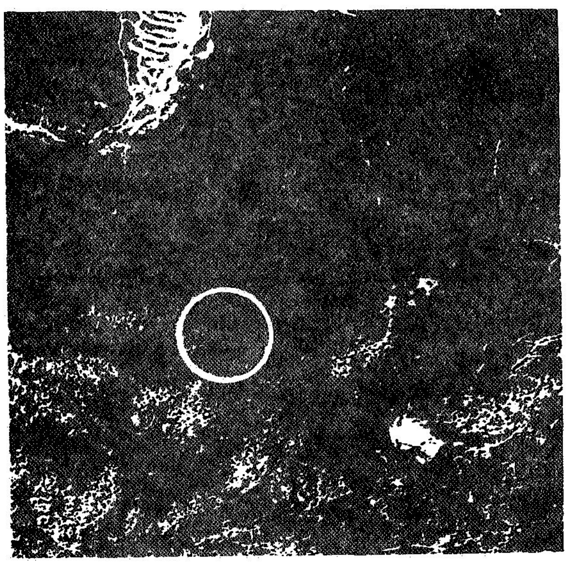


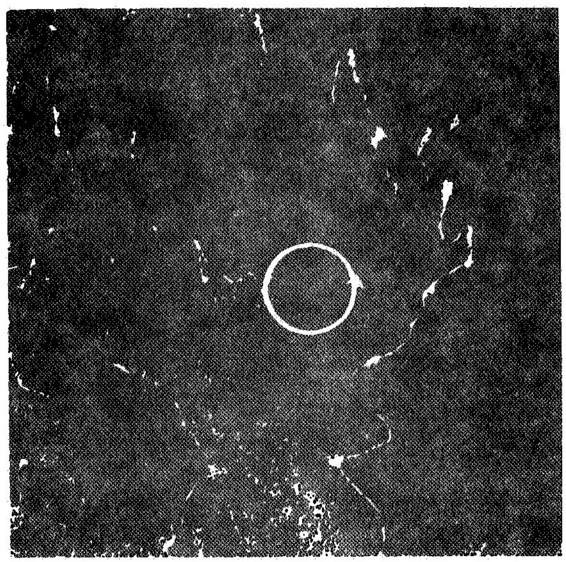
Ekta Aero Infrared Film

Timber Category IVa

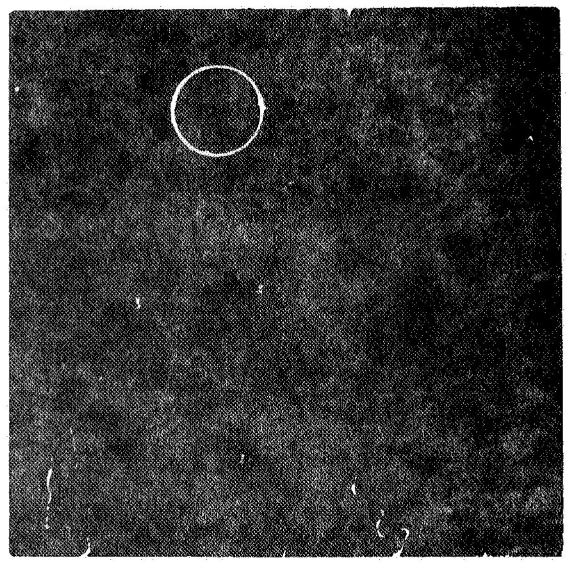
Careful observation indicates that at least one-fourth the area of the plot above is not directly covered by vegetative material; exposed soil is visible over almost half the area in another plot (below). These two stands serve to show almost the entire range of conditions which can be classified in this category. The common characteristic of a noticeable level of commercial conifers (those with a stem diameter at breast height of greater than 10 inches) is indicated by the presence of large, coarse textured crowns; again, there is a rather broad range of density, but in no case do these larger trees account for more than half the crown cover over the entire area.

The objective in improving stands of this sort is obviously to increase the relative amount of growing space occupied by the larger more valuable trees. Already at least half the area is supporting vegetation and the presence of even a few larger trees shows a certain productive potential for the site. With at least twenty percent open area, the forest manager still has much room for timber stand improvement work and stand manipulation.





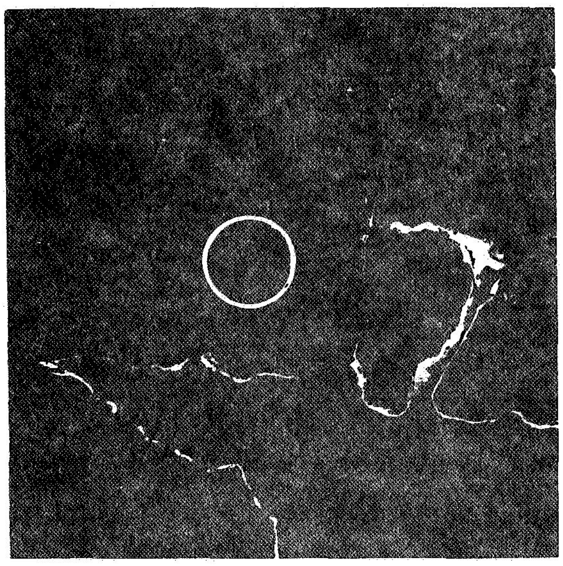
Aerial Ektachrome Film



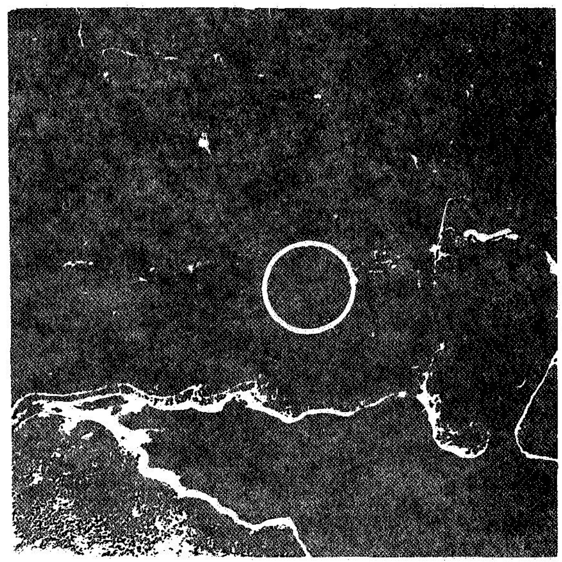
Ekta Aero Infrared Film

Timber Category IVb

The lack of exposed ground in the example above indicates a dense cover of vegetation. A combination of variable crown diameter and texture indicates that this mixed conifer stand is composed of several different age classes. The lighter green tones on the Ektachrome, and light red on Ekta Aero Infrared are a result of hardwood and brushy undergrowth. In the areas above and extending into this plot are numerous striations of bare ground which a forester familar with logging practices of the region would recognize as old skid trails. This in turn suggests a capacity for the area to produce good timber and would help explain the uneven-aged structure of the stand. Recognition of non-coniferous vegetation may influence decisions on the manipulation of this stand for further timber production before more invasion by non-commercial species occurs.



Aerial Ektachrome Film



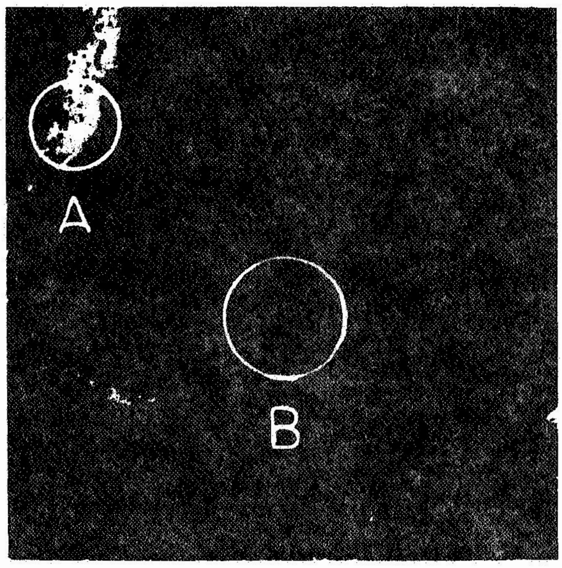
Ekta Aero Infrared Film

Timber Category V

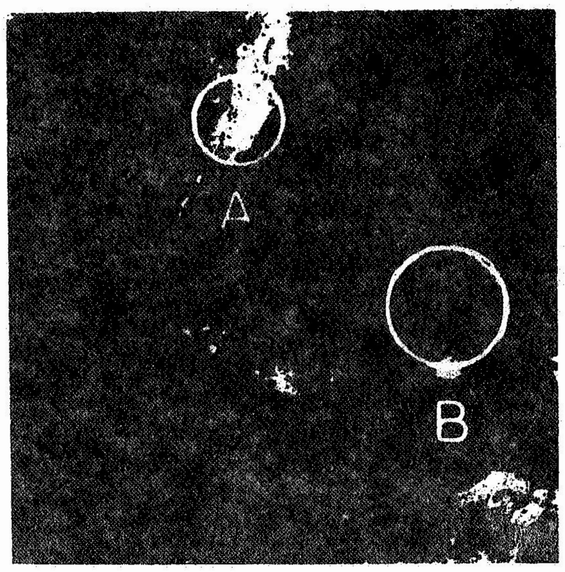
It can be seen that the area above has more than fifty percent cover by contrasting the dark toned vegetation with the lighter toned soil and rock background and noting that over half the plot is dark toned in the vertical view. The distinguishing feature of this category is that the majority of the cover is provided by commercial size (greater than ten inches dbh) conifers. This may be determined by noting the coarse texture caused by the fairly large crowns. In this particular example, additional evidence that the timber is actually of merchantable size is suggested by the cutting boundary which runs through the upper side of the plot.

There are several reasons why a forester would be particularly interested in being able to locate and identify stands which fall into this category. First, such stands contain a great deal of merchantable lumber. Perhaps it may be overmature timber which would succumb to insects or disease or be very susceptible to fire, in which case it may be wise to plan harvesting operations for the area soon. At the same time, silvicultural steps could be taken to improve such conditions as species composition, tree spacing and growth rate. The fact that there is a great amount of large timber on the plot may indicate a site of rather high quality and suggest that intensive management is justified. Specifically, either the present timber can be harvested and a new crop started, or timber stand improvement work can be undertaken with a good probability that the remaining "crop trees" will produce increasing amounts of high quality wood.

In the event that a natural stand of large trees still shows a vigorous growth rate (a condition indicated on the photos by pointed crowns and healthy colored foliage and verified by ground checking sample points located on the photos) the forest land manager may choose to give priority to merely protecting this stand and holding it in reserve until some future biologic or economic condition makes harvesting the wisest move.



Aerial Ektachrome Film



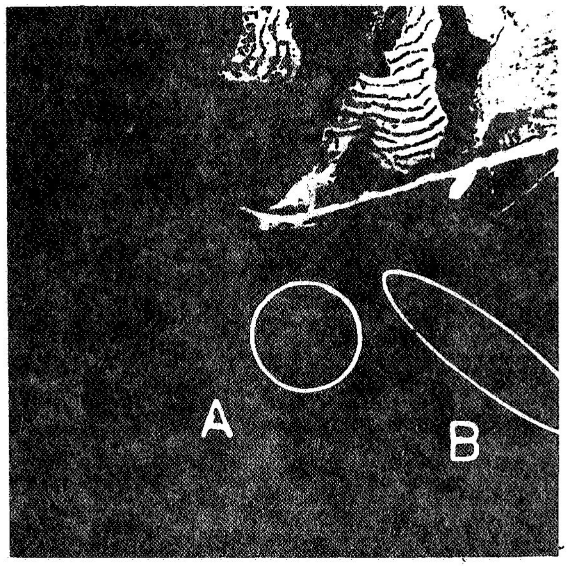
Ekta Aero Infrared Film

Meadow Category

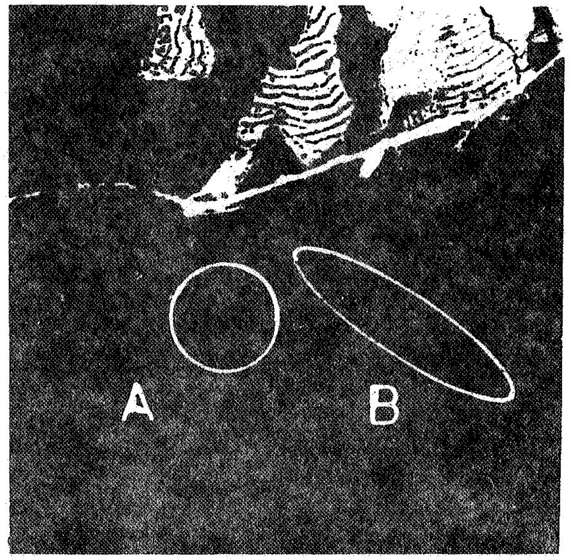
Meadows can be distinguished on aerial photos mainly by their smooth texture and continuity of vegetative cover. This is not to imply that colors or tones are all one shade; in fact, a mottled appearance, due to different reflectance characteristics of plant communities within the type, is often a characteristic aid for identifying this feature (B above). In a forested area a meadow stands out as an open patch in contrast to surrounding trees. Occasionally a broad alluvial fan or exposed dirt or rock surface (as in plot A which illustrates a thin timber stand of Category I) may appear to fit this description, but careful observation of stream beds and of mining or construction activities should prevent confusion with even dried meadow vegetation.

Wet and dry meadows are easily differentiated provided the correct image type is utilized. Ekta Aero Infrared film is particularly valuable for the identification of damp areas, which appear in very bright red tones. On Ektachrome film the wet vegetation appears in dark tones of green, but this feature becomes less distinct when all areas are lush or after the forage has turned brown. The mottled pattern of imaged meadows may ultimately be related to moisture conditions in many cases--the dark tones corresponding to the damp areas and the light tones indicating drier zones. This characteristic often provides a good means of estimating relative forage density and volume.

Although the ability to make species identifications of forage vegetation on small scale imagery has yet to be developed fully, even with the present state of the art, one can get a good impression of the complexity and relative distribution of unique plant communities in a range type. All of this information which may be gleaned from aerial photos, especially when combined with limited ground checking, provides a great aid in the task of wisely managing this resource type. The latest and best information on aerial photo interpretation of rangeland vegetation will be found in companion volumes to this one entitled, "The Evaluation of Rangeland Resources by Means of Multispectral Imagery", by David M. Carneggie.



Aerial Ektachrome Film



Ekta Aero Infrared Film

Brush and Hardwood Vegetation Category

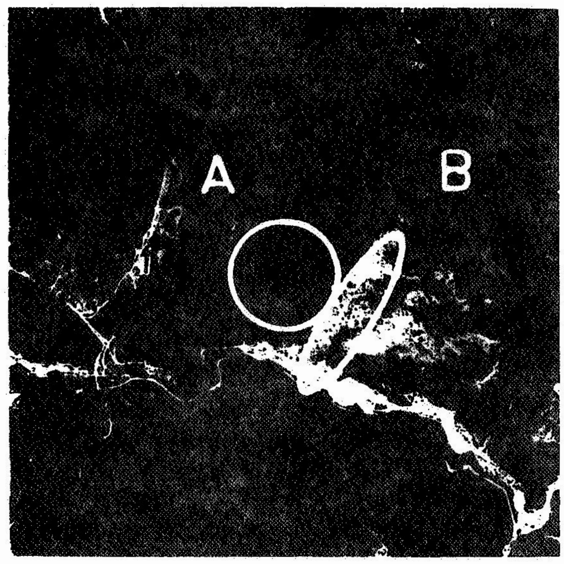
One of the most important type distinctions to be made on aerial photographs of the Bucks Lake Area is that between "brush and hardwoods" and "coniferous forest". The former category is comprised of brush and scrub vegetation together with smaller amounts of riparian species.

Tone is the principle feature used to identify these types. On both Ekta Aero Infrared and Ektachrome the brush has a dull, brownish cast (A above). On Ekta Aero Infrared imagery most live vegetation appears red but brush species tend to appear purplish. Brush on Ektachrome usually appears green, but with a slightly brownish tinge. An alder thicket (B above) illustrates the bright color signature which makes identification of this sort of broadleaf riparian species quite apparent on both film types. The location of these features further aids in their identification. Stream bottoms and other moist or low areas often support riparian vegetation, while brush fields are commonly of a size which will cover several gullies and ridges.

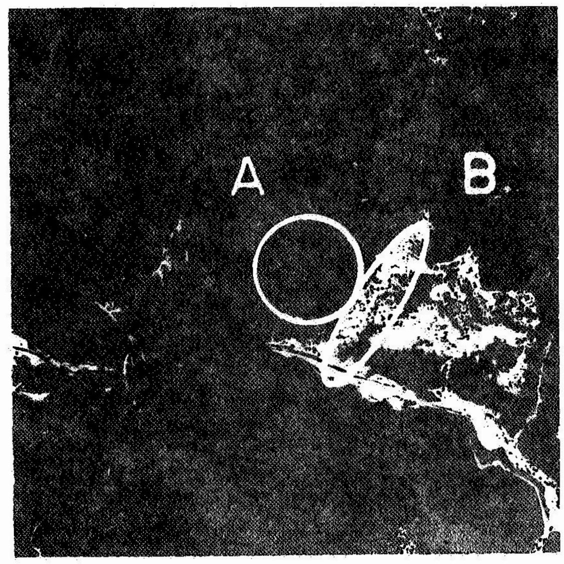
An important feature of brush fields relates to the mixture with timber, either as an invading species which may crowd out desirable tree reproduction or which may be overcome by more tolerant seedlings overtopping it. Particularly in California, vast areas of unproductive brush-covered lands capable of supporting valuable stands of timber may be programmed for reforestation work. The windrowed area in the illustration is an instance of just such clearing and planting activity.

The striking difference in tone between brush species on the north and south side of the hill (plot A) and the unique example (Fig. 5) of contrast in phenological stages indicate a potential for using aerial imagery at the correct time of year for species identification, as well as type classification.

Brush is also important from a wildlife standpoint. Favorable species provide excellent browse for deer, and the "edge effect" and shelter afforded by this cover type often encourage the presence of game.



Aerial Ektachrome Film



Ekta Aero Infrared Film

Non-Vegetation Category

Just as important to the forest manager as a knowledge of all vegetation types is an accurate inventory of non-vegetative features of the forest wildland area he is responsible for managing. These items include exposed soil and rocky areas, lakes and water courses, man-made features and burns and cleared land. Awareness of the extent, type and location of non-vegetated areas is important because of their impact on the forester's planning for timber or forage production, wildlife or recreation development, watershed utilization, etc. Some restrictions are self evident, such as the infeasibility of commercial timber production on high elevation, rocky areas, but the impact of hydraulic mining (B above) or the location of access roads and highways can be largely manipulated, hopefully, to enhance rather than detract from the efficient utilization of the various resources of a given wildland area. For instance, an expanse of rock outcropping may so increase the cost of access road construction that intensive management of certain areas may not be economically sound. On the other hand, the demand for resources in such locations may justify the costs to be incurred. In any event, through proper photo interpretation the forester would be much better informed of the trouble spots to be encountered and thus would be better able to arrive at sound conclusions in planning and executing the project.

On both Ektachrome and Ekta Aero Infrared films, rocky areas (B above) are easily identified by their light tone (white or brownish cream to grayish blue) and paucity of vegetative cover. Water features are readily discerned on Ekta Aero Infrared by their brilliant dark blue tones whereas Ektachrome presents a truer rendition of actual colors (note stream through lower tip of plot B). Man-made features are best distinguished by their shape and regular appearance, pattern, and often contrasting color with natural features. Recent burns are readily spotted, especially on Ekta Aero Infrared film, due to the contrast of vegetation with exposed or ash covered soil or rock surfaces. Bare soil may vary in color, but high reflectance of wavelengths in the 0.4 to 0.7 micron region (compared to plant covered areas) should suggest the true nature of the feature.